Journal

of

THE ROYAL AERONAUTICAL SOCIETY

OCTOBER 1959

CONTENTS

NOTICES

THRUST REVERSAL FOR JET AIRCRAFT — R. H. COLLEY

DEFINITIONS AND TERMS RELATING TO AIRCRAFT CONTROL SYSTEMS AND COMPONENTS — H. R. HOPKIN AND H. H. B. M. THOMAS

DAMAGE TO AXIAL COMPRESSORS — J. DUNHAM

INFLAMMABILITY AND ELECTRICAL STUDIES OF FOAMS WHICH MAY OCCUR AT ALTITUDE BY DE-AERATION OF AVIATION TURBINE FUELS — B. V. POULSTON AND A. THOMAS

BASIC PRINCIPLES OF RADAR WITH PARTICULAR REFERENCE TO AIRCRAFT AND MISSILE APPLICATIONS — F. D. BOARDMAN

TECHNICAL NOTES

Pressure Loss Data for Crimped Metal Strip Matrices—B. C. LINDLEY. The Inertial Effects of Springs in Oscillation Experiments to Determine Damping —M. D. FROST.

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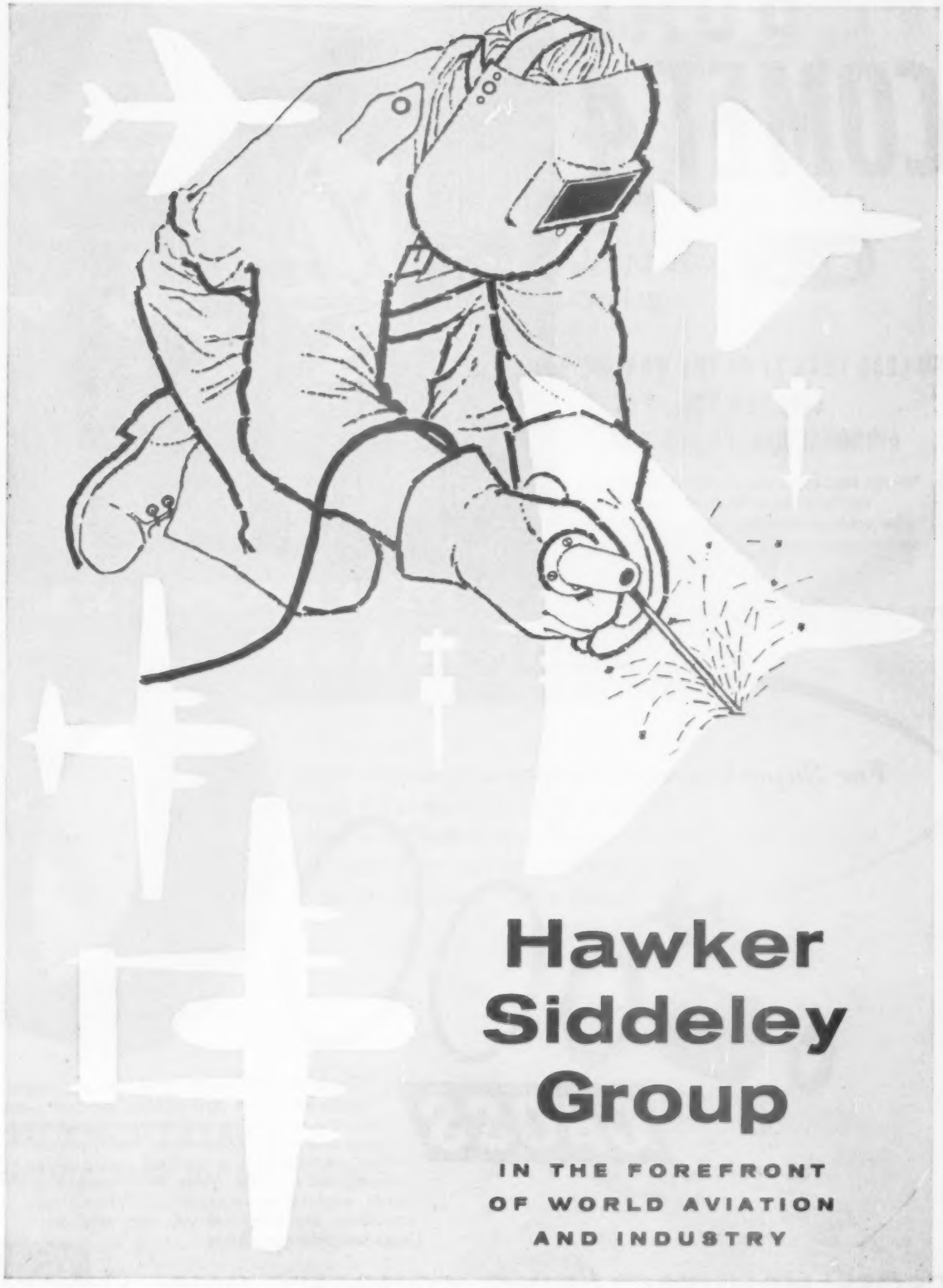
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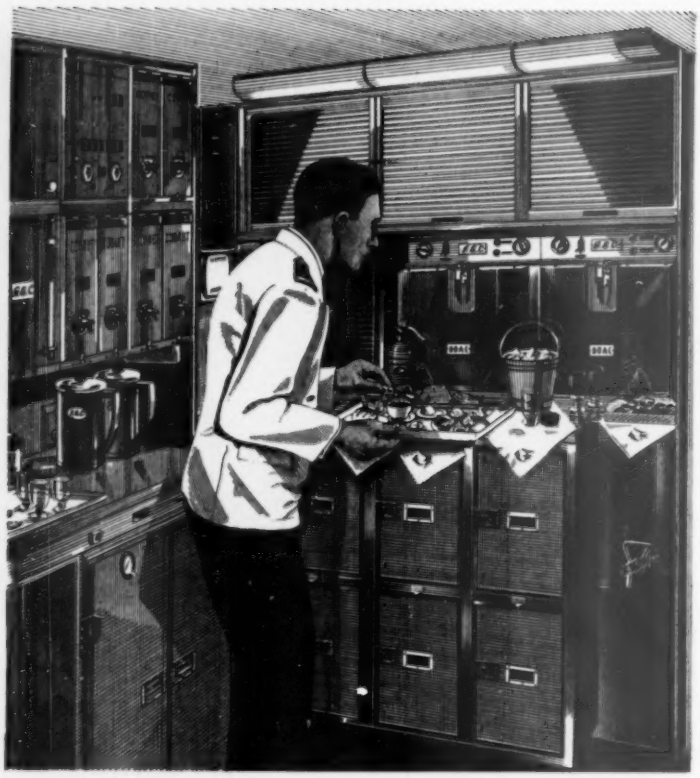

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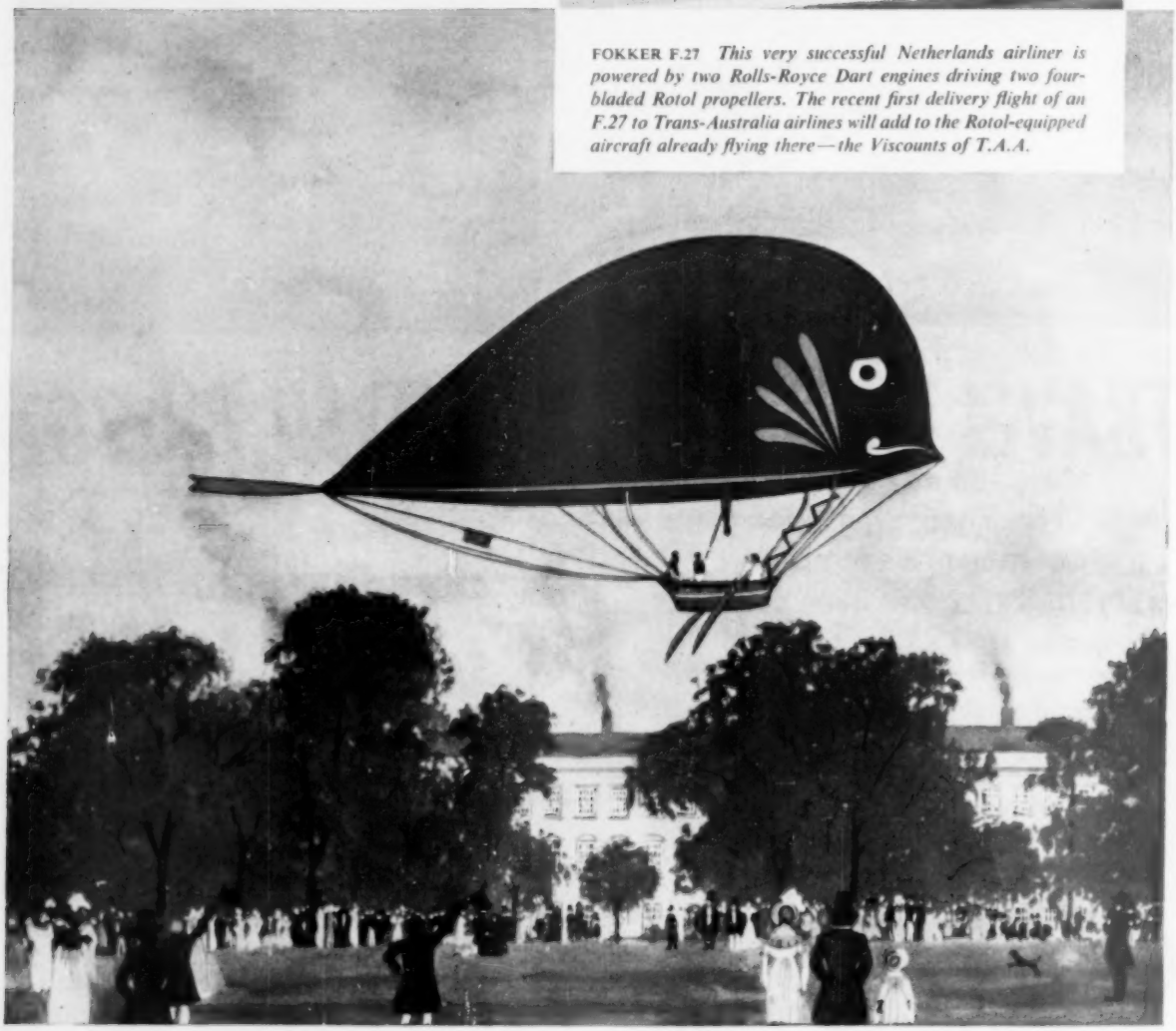

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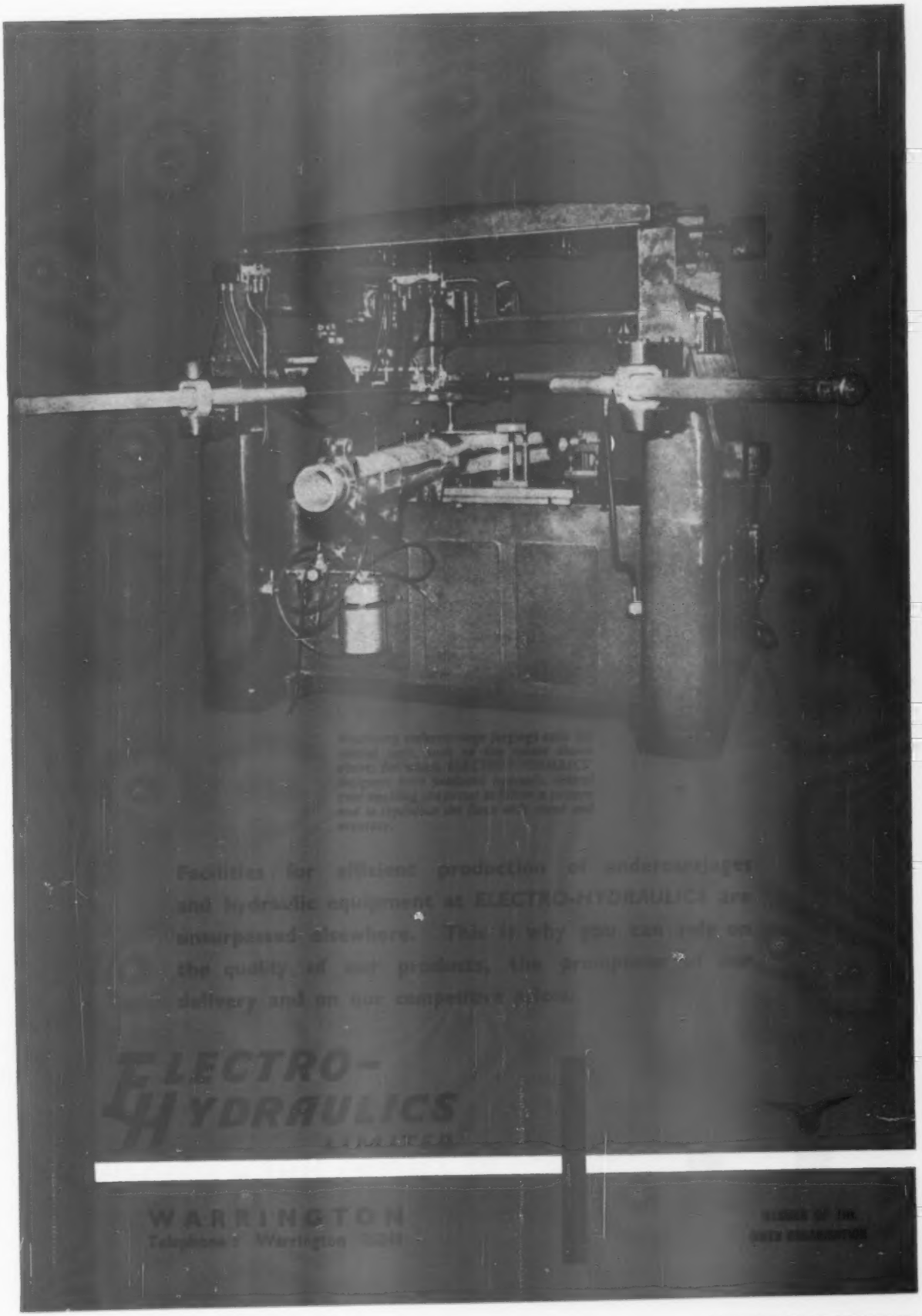
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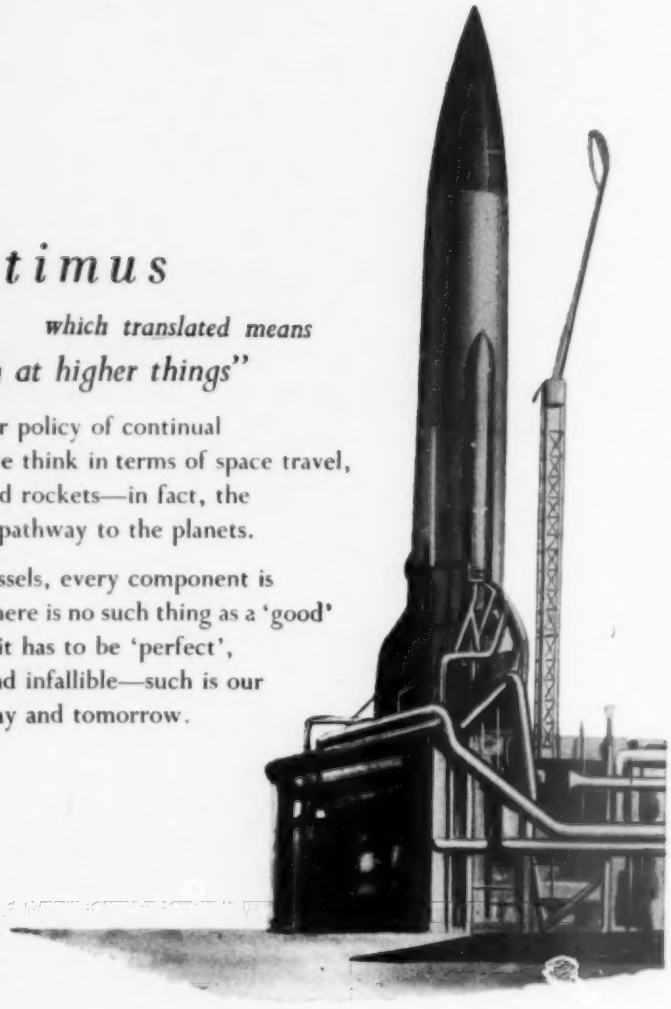

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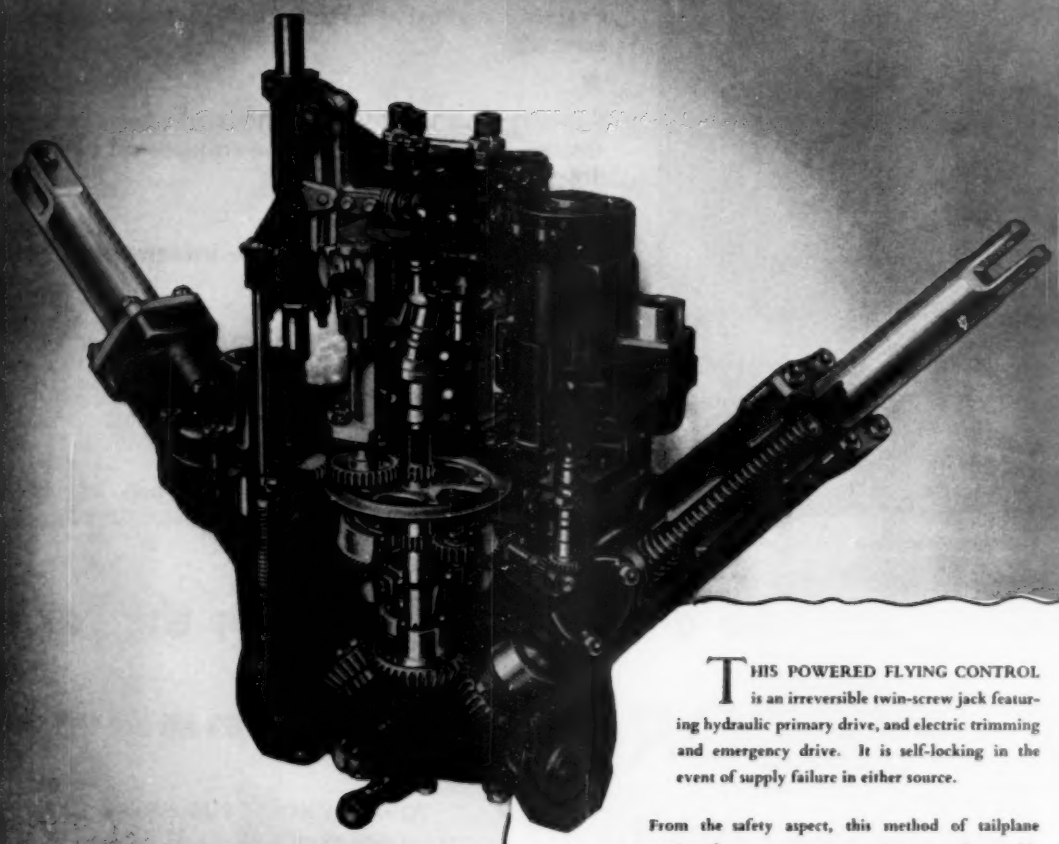

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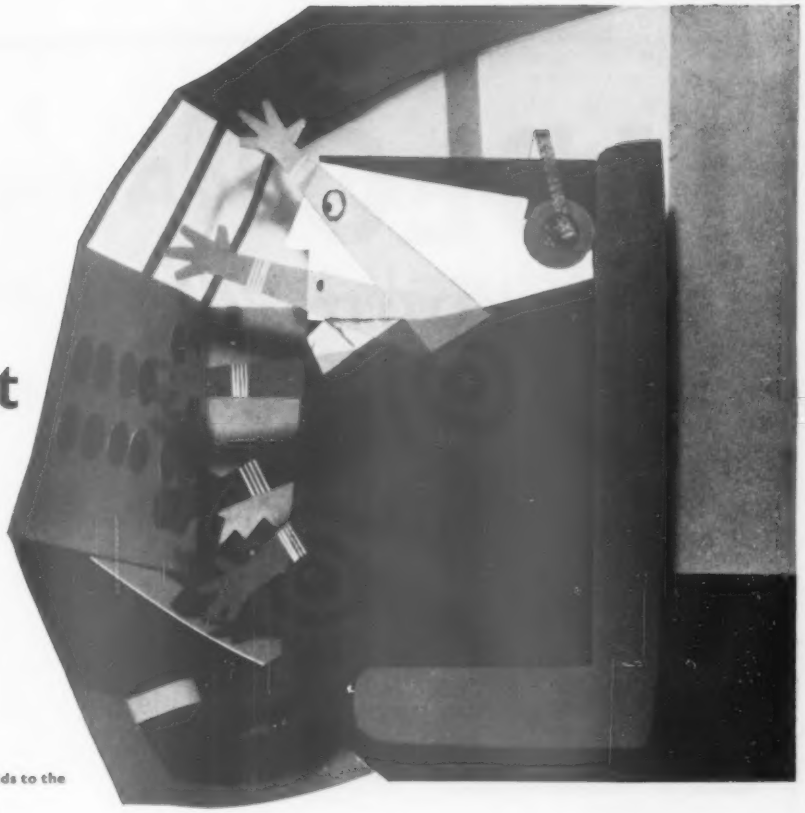

The IFALPA delegate speaking on point source aids to the ICAO Special Meeting, Montreal, February 1959

. . . . "**It is a most unfortunate time to have to be fiddling with a receiver.** In order to tune in this type of station, you must switch off all of your other communications or else you will never pick up the Identification. One man in the cockpit is completely concerned with just one thing: tuning in the station – pressing his hands against his ears until he *can* identify it. The other man takes over the entire communications guard; continuously receiving clearances stepping the ship down, and also slowing it down; at the same time he is also operating a check list; this calls for conversation between himself and the other pilot if he can finish with his station identification. It is a very poor time to be distracted and pre-occupied with tuning a facility . . . there are eight holding stacks and of these six are non-directional beacons and the other two are intersections of radials from VORs. Holding on an intersection of two radials, you will be in a pattern something like this – one minute on this leg, a one minute turn, one minute on this leg, another minute turn and you are back where you started. On your Symbolic Display you centre the needle indicating the VOR radial from the left side; the VOR on the other side has a needle that is off-set, and as you approach the intersection, the needle on the other one will come into the centre—only at that one instant do you know exactly where you are. You then punch a stop watch and start a turn, using your directional Gyro and Turn Indicator—incidentally, you must hold your altitude with considerable precision because there are people above and below you in the stack. As soon as you leave this point both needles will be at various positions on the face of the dials and extremely difficult to interpret. As you come back into your pattern, the needle on the left should centre itself. If it does not you have wind drift, and you have a minute in which to correct it and bring it back into the centre. **'IS PICTORIAL PRESENTATION DESIRABLE?'** I would say that it most definitely is. There is only one instant in this four minute pattern when you know exactly where you are, and that is only if within that minute you have been able to re-align yourself". . .

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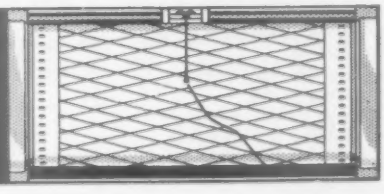

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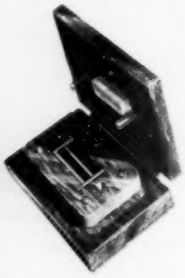

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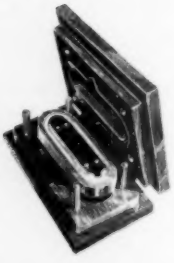

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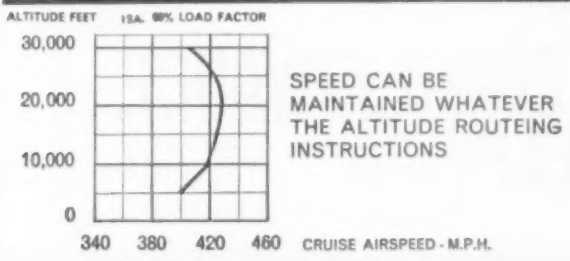

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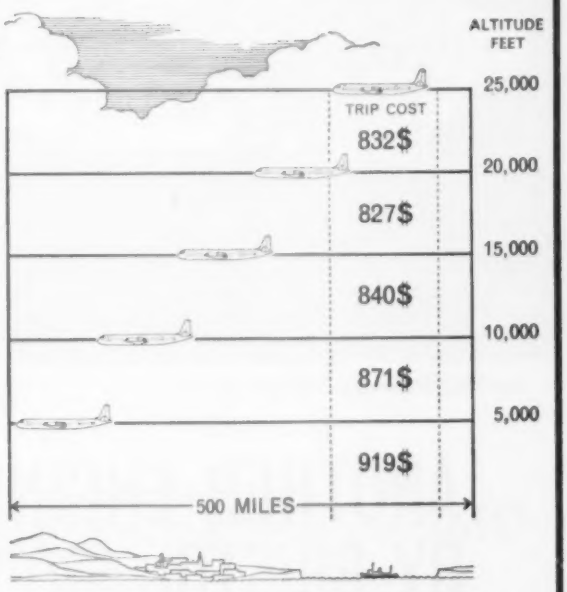

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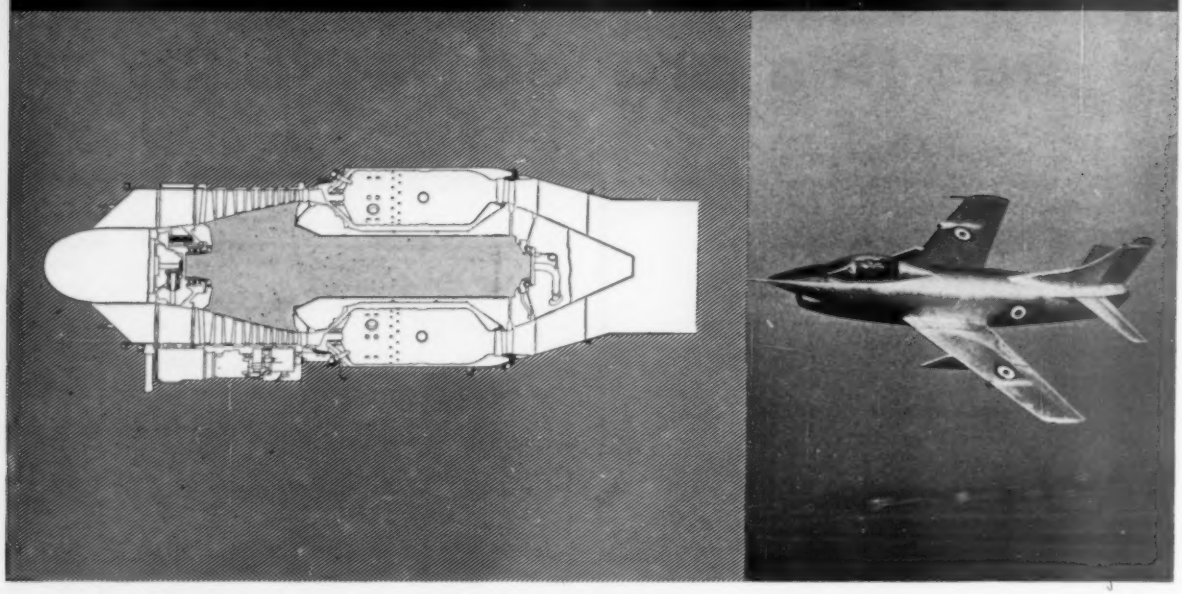

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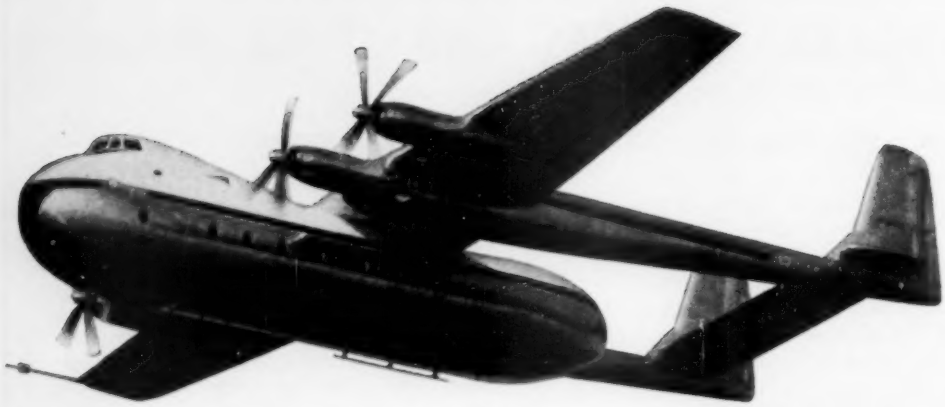

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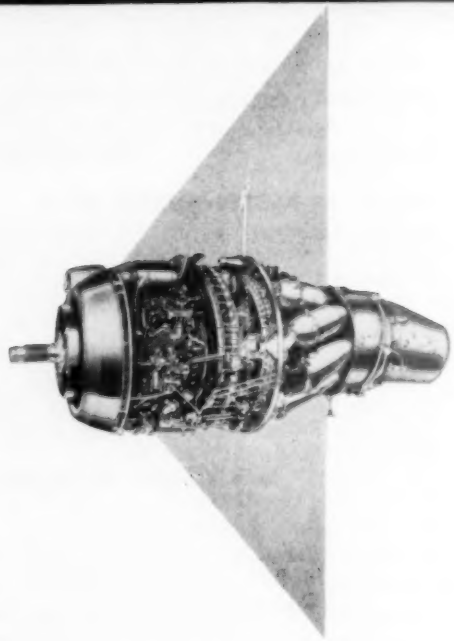

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CONTENTS

PAGE

Notices XLV

New Policy for Lectures—New Housing for Nash Collection—Membership of the Canadian Aeronautical Institute and United Kingdom Income Tax Relief—The Fifteenth British Commonwealth Lecture—British Association Granada Lectures—Heat Transfer and Fluid Mechanics Institute—School of Welding Technology—Diary—Associate Fellowship Examination Results—Agricultural Aviation Group—Training Center for Experimental Aerodynamics—Supplement to Oxford English Dictionary—Acknowledgment—News of Members—Seventh Anglo-American Aeronautical Conference—Elections—Eleventh Conference of the British Occupational Hygiene Society—Lecture Theatre Appeal—Summaries of Lectures: Main Lecture on 27th October; Man-Powered Aircraft Group Inaugural Meeting, 30th October—Aircraft Gas Turbine Course—Symposium on Aerodynamic Capture of Particles—Journal Binding—Changes of Address and Appointment—"Aircraft Engineering" Volumes Reprinted.

Thrust Reversal for Jet Aircraft — R. H. COLLEY — 563

Definitions and Terms Relating to Aircraft Control Systems and Components — H. R. HOPKIN and H. H. B. M. THOMAS — 572

Damage to Axial Compressors — J. DUNHAM — 576

Inflammability and Electrical Studies of Foams which may occur at Altitude by De-Aeration of Aviation Turbine Fuels — B. V. POULSTON and A. THOMAS — 581

Basic Principles of Radar with Particular Reference to Aircraft and Missile Applications — F. D. BOARDMAN — 589

Technical Notes 597

Pressure Loss Data for Crimped Metal Strip Matrices—B. C. LINDLEY. The Inertial Effects of Springs in Oscillation Experiments to Determine Damping—M. D. FROST.

Graduates' and Students' Section 607

The Library 608

REVIEWS: Fire Control Principles—Hyperstatic Structures—Applied Hydrodynamics—Introduction to Monopulse—Metals for Supersonic Aircraft and Missiles—Materials for Rockets and Missiles.

ADDITIONS TO THE LIBRARY. REPORTS.

All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., Hon.F.C.A.I., F.I.A.S., F.R.Ae.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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The Royal Aeronautical Society

(Founded 1866)

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October 1959.

STOP PRESS: At its Meeting on Thursday 24th September 1959, the Council decided to go ahead with the construction of the Lecture Theatre. The Contract has been awarded to Holland and Hannen and Cubitts Ltd., and the work will start early in October and will be completed within a year. Although the full amount required has not yet been subscribed, sufficient has been received for the Council to determine on action. Members who have delayed sending in their contributions are earnestly asked to send them now.

NOTICES

New Home for the Nash Collection

British European Airways has generously made available to the Society temporary accommodation for the Nash Collection of Historic Aircraft in the new extension to the B.E.A. Engineering Base at London Airport. The excellent working conditions at the Base should enable the volunteer teams of the Historic Aircraft Maintenance Group to make faster progress during the coming Winter with the work of restoring the aircraft. The Society hopes that the aircraft may be moved from Hendon to London Airport within the next month.

The Council is most grateful to the Chairman and Board of B.E.A. for making available this temporary accommodation and also wishes to express sincere thanks to the Air Ministry for permitting the aircraft of the Nash Collection to be housed in No. 106 Hangar at Hendon for the past two years.

Membership of the Canadian Aeronautical Institute and United Kingdom Income Tax Relief

The Society has been advised by the Canadian Aeronautical Institute that that body has been approved for the purposes of Section 16 of the British Finance Act 1958. This means that members resident in the United Kingdom who are also members of the Canadian Aeronautical Institute may obtain relief on subscriptions paid to the C.A.I. beginning with the year to 5th April 1959. Those entitled to claim should obtain Form P358 from their local tax office as soon as possible. The conditions governing this relief are exactly the same as those applicable to the Society which were published in the February 1959 JOURNAL (p. XII).

The Fifteenth British Commonwealth Lecture

The Fifteenth British Commonwealth Lecture will be held on Thursday 19th November at 6 p.m. at the Institution of Mechanical Engineers, 1 Birdcage Walk, S.W.1. Tea will be served at 5.30 p.m.

The subject will be "Some Recent Progress in Air Survey with Special Reference to Newly Developed Territories," and will be given by Mr. W. P. Smith, M.B.E., B.A., F.R.I.C.S., Director, Fairey Air Surveys Ltd.

British Association Granada Lectures

A new series of annual lectures organised by the British Association for the Advancement of Science and sponsored by Granada TV Network Ltd., on the theme "Communication in the Modern World," will be inaugurated at Guildhall in October. Three lectures will be given, as follows:—

13th October—Sir Edward Appleton, Principal and Vice-Chancellor of Edinburgh University, will speak on the significance of long-range communication and the exploration of space.

19th October—Dr. Edward R. Murrow, the well-known American Commentator will talk of the impact of television and radio in the field of politics and public affairs in a democracy.

27th October—Sir Eric Ashby, Vice-Chancellor, Queen's University, Belfast, will talk about methods of presenting scientific information to the public.

The Lectures will be held in Guildhall at 8.30 p.m. Members wishing to attend should apply for tickets at the following address:— British Association Granada Lectures, 36 Golden Square, London W.1.

New Policy for Lectures

The increase in the number of lectures being given before the Society—a trend which will continue as new Groups and Sections are formed—together with increased costs of publication, has caused the Council to adopt a new policy for the publication of lectures.

Hitherto lectures have been recommended by the Lectures Committee but, in addition the Council now invites members of the Society—and non-members—to submit papers for presentation as lectures. Such papers should be sent, in duplicate with a summary of 200-400 words, to the Secretary.

Previously all Main Lectures given before the Society have been assured of publication in the JOURNAL but, beginning with this 1959-1960 Session, publication will be guaranteed of only the Commonwealth, and the Blériot, Lanchester and Wilbur Wright Memorial Lectures and, the Inaugural Memorial Lecture at a Branch.

The publication of all other lectures will be made on the recommendation of specially appointed referees and the Lectures Committee; suitable lectures may be published in THE AERONAUTICAL QUARTERLY.

If a lecture is not recommended for publication the Society will relinquish its copyright. The decision on publication will be taken as quickly as possible after delivery of the lecture and, if a lecture is not to be published in the JOURNAL or the QUARTERLY, copies will be placed in the Library where they will be available on loan to members. This may not be possible in all cases as authors of some of the lectures given in the Library (those known originally as Section Lectures) do not always prepare a written paper.

Advance copies of Main Lectures will no longer be printed but a limited number of copies will be prepared for those wishing to take part in discussions.

Summaries of *all* lectures will be published in the JOURNAL, if possible well before the lecture is given. No summary will be printed of the Symposium on "Operational Problems of Take-Off and Landing," which was held on 4th September in conjunction with the Sixth Meeting of the Commonwealth Advisory Aeronautical Research Council, because the introductory papers and discussion will be published in the JOURNAL.

The Council regrets that circumstances make necessary these changes in policy but hopes that they will result in a better service to members.

Heat Transfer and Fluid Mechanics Institute

The 1960 meeting of the Heat Transfer and Fluid Mechanics Institute will be held from 15th to 17th June 1960 at Stanford, California.

Papers are particularly invited on:—thermal-radiation problems in space technology; fluid problems peculiar to low gravity environments, rotating fluid systems; flows not in thermodynamic equilibrium; time-dependent viscous flows; separated flows; origins of turbulence; and turbulent mixing and diffusion. Titles and abstracts must be submitted by **1st December 1959** and final papers by **15th February 1960.**

Papers should be submitted to Walter G. Vincenti, Department of Aeronautical Engineering, Stanford University, Stanford, California.

School of Welding Technology

October courses at the School of Welding Technology will cover Pressure Vessels and Pipework, Control of Distortion, and Residual Stresses. Details may be obtained from J. L. Sanders, Technical Officer, The Institute of Welding, 54 Prince's Gate, Exhibition Road, London S.W.7.

DIARY

LONDON

27th October

MAIN LECTURE—Aircraft Fatigue—A Survey of Current Thought. R. J. Atkinson. Church House, Westminster, S.W.1. 7 p.m. *See summary.*

29th October

SPECIAL GENERAL MEETING—The Society and The Helicopter Association. 4 Hamilton Place. 6.30 p.m.

30th October

MAN POWERED AIRCRAFT GROUP—INAUGURAL MEETING—Resumé of the Theory and Practice. H. B. Irving, Dr. D. R. Wilkie, T. R. F. Nonweiler, B. S. Shenstone. Library, 4 Hamilton Place. 7 p.m. *See summary.*

13th November

AGRICULTURAL AVIATION GROUP LECTURE—General Discussion on the International Conference at Cranfield. Library, 4 Hamilton Place. 7 p.m.

17th November

LECTURE—Magnetogasdynamics. Dr. J. A. Shercliff. Library, 4 Hamilton Place. 7 p.m.

19th November

FIFTEENTH BRITISH COMMONWEALTH LECTURE—Some Recent Progress in Air Survey with Special Reference to Newly Developed Territories. W. P. Smith. The Institution of Mechanical Engineers, 1 Birdcage Walk, S.W.1. 6 p.m. (Tea at 5.30 p.m.)

24th November

LECTURE—Heat and Mass Transfer in Aeronautical Engineering. Professor D. B. Spalding. Library, 4 Hamilton Place. 7 p.m.

26th November

THIRD LANCHESTER MEMORIAL LECTURE—Some Developments in Boundary Layer Research in the last Thirty Years. Professor Dr. H. Schlichting. Church House, Westminster, S.W.1. 6 p.m. (Tea at 5.30 p.m.)

27th November

MAN POWERED AIRCRAFT GROUP LECTURE—Man as an Aero Engine. Dr. D. R. Wilkie. Library, 4 Hamilton Place. 7 p.m.

ASTRONAUTICS AND GUIDED FLIGHT SECTION

22nd October

Problems of Interplanetary Navigation and Atmospheric Re-Entry. T. R. F. Nonweiler. Church House, Westminster, S.W.1. 7 p.m.

3rd November—Cancelled.

GRADUATES' AND STUDENTS' SECTION

7th October

Lunar Probes. J. E. Allen. Library, 4 Hamilton Place. 7.30 p.m.

28th October

The Setting of Aircraft Specifications. R. H. Whitby. Library, 4 Hamilton Place. 7.30 p.m.

11th November

The Flight Testing of Rotorcraft. Sqn. Ldr. W. R. Gellatly. Library, 4 Hamilton Place. 7.30 p.m.

20th November

Winter Dance. 4 Hamilton Place.

BRANCHES

5th October

Derby—The Black Knight (with film). D. J. Lyons. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

Henlow—Man Powered Aircraft. B. S. Shenstone. Building 62, Technical College, Henlow. 7.45 p.m.

6th October

Boscombe Down—Man-Powered Flight. B. S. Shenstone. Lecture Hall, A. & A.E.E. 5.30 p.m.

7th October

Bristol—Sustained Flight at High Altitude by Free Balloons. Professor Powell. Filton House. 6 p.m.

Christchurch—Satellites—The Present Position and Future Possibilities. Dr. L. R. Shepherd. Kings Arms Hotel. 7.30 p.m.

Swindon—Human Elements of High Speed Flight. Dr. J. Gabb. The College, Victoria Road. 7.30 p.m.

Weybridge—Fatigue in Modern Aircraft Structures. D. M. McElhinney. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6.10 p.m.

13th October

Luton—Instruments and Flight Control Systems for Transport Aircraft. W. H. McKinley. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.

14th October

Brough—Experiences of an Airline Pilot. Capt. O. P. Jones. Royal Station Hotel Writing Room. 7.30 p.m.

17th October

Luton—Visit to Shuttleworth Collection, Old Warden.

19th October

Henlow—Blind Landing. W. J. Charnley. Building 62, Technical College. 7.45 p.m.

22nd October

Isle of Wight—Air Traffic Control and Jet Operations. H. E. Smith. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

27th October

Luton—Debate. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.

28th October

Christchurch—The Development of the Viscount Fuel System. G. B. Hustings. Kings Arms Hotel. 7.30 p.m.

Preston—Glass and its Uses. Dr. A. J. Holland. R.A.F.A. Hall, Preston. 7.30 p.m.

Weybridge—Kinetic Heating of Aircraft Structures. A. W. Kitchenside. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6.10 p.m.

29th October

Belfast—The Importance of Reliability in Modern Technology. Air Vice-Marshal A. V. Hutton. Lecture Hall LG8, David Keir Building, Queen's University. 7 p.m.

31st October

Luton—Visit to de Havilland Engine Company Test Beds, Hatfield.

2nd November

Boscombe Down—Inertia Navigation. J. E. Pateman. Lecture Hall, A. & A.E.E. 5.30 p.m.

Henlow—Black Knight. H. G. R. Robinson. Building 62, Technical College. 7.45 p.m.

Derby—Fourth Sir Henry Royce Memorial Lecture—Power for an Airline. B. S. Shenstone and H. G. Rossiter. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

3rd November

Luton—Materials for Supersonic Aircraft. G. Meikle. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.

4th November

Bristol—Brains Trust. Sir George R. Edwards, Sir George Gardner, E. C. Bowyer, Peter Twiss, Peter G. Masefield. Question Master: Professor A. R. Collar. Filton House, 6 p.m.

Swindon—Power from Nuclear Energy. Dr. M. D. Wood. The College, Victoria Road. 7.30 p.m.

6th November

Brough—Annual Dinner and Dance, Jackson's Ballroom, Hull.

11th November

Bristol—Film Show. Filton House. 6 p.m.

Brough—Sixth Cayley Memorial Lecture—The Work of the R.A.E., Bedford. Sir George Gardner. Royal Station Hotel Writing Room. 7 p.m.

12th November

Isle of Wight—Annual Dinner. Hotel Ryde Castle. Principal Guest: P. G. Masefield.

16th November

Henlow—Flight Development of a Modern Prototype Aircraft. C. F. Bethwaite. Building 62, Technical College. 7.45 p.m.

17th November

Christchurch—Lecture by Maurice Brennan. Kings Arms Hotel. 7.30 p.m.

18th November

Preston—Aircraft Production Techniques. L. G. Burnard. R.A.F.A. Hall, Preston. 7.30 p.m.

Weybridge—Flight Testing at Supersonic Speeds. Wing Cdr. R. P. Beamont. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6.10 p.m.

20th November

Luton—Annual Dinner, Leicester Arms Hotel.

24th November

Belfast—Film Night. Lecture Hall LG8, David Keir Building, Queen's University. 7 p.m.

Associate Fellowship Examination Results

The following Candidates were successful in the Associate Fellowship Examination held in June 1959:—

Part I—United Kingdom

D. N. Bullock. Strength of Aircraft Materials and Theory of Structures, Theory of Machines.

R. L. A. Cardozo. Pure Mathematics, Mechanics, Physics, Thermodynamics, Theory of Machines; T. Coxall. Physics.

C. M. Jagtiani. Theory of Machines.

B. Potter. Physics, Aerodynamics, Thermodynamics.

J. N. Ramsden. Mechanics, Aerodynamics, Strength of Aircraft Materials and Theory of Structures.

P. L. Schiefelbein. Thermodynamics, Theory of Machines.

P. M. Toor. Aerodynamics.

Part I—Abroad

E. M. Aldworth (Rhodesia). Strength of Aircraft Materials and Theory of Structures.

B. D. Dolli (Madras). Thermodynamics.

A. Kumar (Delhi). Thermodynamics.

B. B. Julka (Bombay). Pure Mathematics, Mechanics, Physics, Thermodynamics, Theory of Machines.

M. Madhavan (Poona). Strength of Aircraft Materials and Theory of Structures, Theory of Machines.

Y. K. Nagaraja (Bangalore). Pure Mathematics, Mechanics, Physics, Strength of Aircraft Materials and Theory of Structures.

M. H. K. Tewari (Bangalore). Thermodynamics, Theory of Machines.

Part II—United Kingdom

N. J. Chamberlain. Theory of Structures A, Theory of Structures B.

M. A. C. Deans. Theory of Structures A, Theory of Structures B; A. W. Delobelle. Theory of Structures A, Theory of Structures B.

C. M. Jagtiani. Theory of Structures A, Theory of Structures B.

R. McKay. Theory of Structures A, Theory of Structures B, Theory of Structures C.

R. S. Randall. Aerodynamics A, Theory of Structures A, Thermodynamics and Theory of Machines.

M. Ward. Theory of Structures A, Thermodynamics and Theory of Machines.

Part II—Abroad

P. L. Bajaj (Delhi). Thermodynamics and Theory of Machines.

R. Kumar (Madras). Thermodynamics and Theory of Machines.

K. G. Pillai (Delhi). Thermodynamics and Theory of Machines, General Design, Piston and Turbine Engines.

G. A. Wardill (New York). Thermodynamics and Theory of Machines.

J. G. Wilson (Vancouver). Air Transport, Operational Air Transport.

Mr. Grahame-White's Collection of Photographs

The newly-formed Historical Section of the Royal Aeronautical Society has received its first substantial gift.

Mrs. Claude Grahame-White has given to the Society, subject to certain deductions, the whole of her husband's large and extremely interesting collection of framed and unframed photographs. These form a valuable link with the earliest days of flying in this country and in France. There are also a number taken during Mr. Grahame-White's visit to the United States in 1910.

The Council deeply appreciates this generous gift from Mrs. Grahame-White.

Agricultural Aviation Group

The Provisional Committee of the Agricultural Aviation Group, which will act on behalf of the Group until an Annual General Meeting is called and the election of officers takes place, is as follows:—

S. W. G. Foster, A.F.R.Ae.S. (Design Consultant) *Chairman.*
R. C. Amsden, Companion (Head of Applications Dept., Fisons Pest Control).
F. C. Clay, A.F.R.Ae.S. (Chief Draughtsman, Project and Development Branch, B.E.A.).
E. D. King, A.F.R.Ae.S. (Research Engineer, Hunting Engineering Ltd.)
E. H. Smith, A.F.R.Ae.S. (Chief Technician, Baynes Aircraft Interiors).
H. G. Winton, A.F.R.Ae.S. (Design Surveyor, Air Registration Board).
R. Truslove (Works Manager, Fison-Airwork).
Miss E. C. Pike, A.F.R.Ae.S. (R.Ae.S.), *Secretary.*

Group meetings planned for the 1959-1960 Session will cover such subjects as economic factors, planning of operations, biological factors, choice of aircraft, pilot training and a film evening. Details will be given in "The Diary" each month.

Any member interested in joining the Group and in receiving notice of its activities should write to the Secretary of the Society. Visitors are welcome to meetings.

Supplement to Oxford English Dictionary

The following is the third list of aeronautical terms for the Supplement to the Oxford English Dictionary for which assistance in tracing early references is required. If members know of an earlier use than that given for any word in the following list they are asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page. The first two lists were published in the June and August Journals.

air alert	1941	*Times Weekly*
air ambulance	1921	*Aeronautics*
air-bomber	1935	H. G. Wells *Things to Come*
airborne (of aircraft)	1909	Charles M. Doughty *The Cliffs*
air chart	1948	*Journal of the Institute of Navigation*
air drop (ping)	1950	Baltimore *Sun*
airfield	1929	*Concise Oxford Dictionary*
air freight	1942	O. J. Lissitzyn *International Air Transport*
air freighter	1941	*Flight*
air gunner	1939	*Flight*
air gunnery	1942	W. Simpson *One of Our Pilots is Safe*
air hostess	1934	Baltimore *Sun*
airmail edition, air edition	1944	*Times Weekly*
air mile	1945	*Yorkshire Post* (we have aircraft mile 1942)

News of Members

J. A. Boddy (*Student*) formerly with Avro Aircraft Ltd., Canada, is now on the Technical Staff of R.C.A. Missile Electronics and Controls Department, Burlington, Mass.

J. Brenchley (*Associate Fellow*) formerly a Senior Stressman, Helicopter Division, Saunders-Roe Ltd., is now with Bristol Aircraft Ltd.

R. G. Carlton (*Graduate*) formerly a Design Technician, Rocket Division, de Havilland Engine Co. Ltd., is now with the General Electric Company of Erith, Kent, in the Steam Turbine Division.

D. A. Collings (*Student*) formerly a Design Technician, Weapons Research Division, A. V. Roe and Co. Ltd., is now a Stressman, Light Aircraft Division, Short Brothers and Harland Ltd.

Graham C. Cook (*Graduate*) having successfully completed the Diploma Course at Cranfield, is now an Engineer working on re-entry problems, with de Havilland Propellers Ltd., London.

Eric H. Crudden (*Associate*) formerly a Senior Design Engineer, Lockheed Aircraft Corporation, California, is now a Design Engineer, Grumman Aircraft and Engineering Corporation, New York.

J. Deakin (*Graduate*) formerly at Bristol University, is now with Sir W. G. Armstrong Whitworth Aircraft Ltd., as a Flight Test Aerodynamicist.

P. N. Dent (*Associate Fellow*) formerly in the Technical Services Department, Rolls-Royce (Scottish Factories) Ltd., is now a Senior Engineer, Control Section, English Electric Aviation Ltd., Stevenage.

R. De Winton (*Graduate*) formerly with the de Havilland Aircraft Co. Ltd., has been Commissioned in the Royal Canadian Air Force, stationed at Centralia, Ontario.

Wing Commander A. E. Foster (*Associate Fellow*) formerly Senior Technical Officer, Tangmere, is now at R.A.F. Honington as a Senior Technical Officer.

C. R. Foster (*Student*) after successfully completing the Diploma Course at the College of Aeronautics has returned to Sir W. G. Armstrong Whitworth Aircraft Ltd., Whitley, as Structures Engineer (Aircraft).

Sir George Gardner (*Fellow*) formerly Director of the Royal Aircraft Establishment, Farnborough, has been appointed Controller of Aircraft at the Ministry of Supply.

M. H. C. Gordon (*Associate Fellow*), General Manager, Helicopter Division, Saunders-Roe Ltd., has been appointed to the Board of Directors.

S. W. Greenwood (*Associate Fellow*) has left the College of Aeronautics to become a Free Lance Writer and Consultant and will be living at West Clandon.

A. W. Gregg (*Associate*) formerly Technical Publications Officer, Normalair Ltd., is now Personal Assistant to the Managing Director and Public Relations Manager of Westland Aircraft Ltd., Normalair Ltd., Westland Engineers Ltd., and the Unique Balance Co. Ltd.

W. G. Hearle (*Associate Fellow*) formerly the Chief Estimator, Chester Branch, de Havilland Aircraft Co. Ltd., has been transferred to Hatfield as Contracts Officer.

W. F. Hilton (*Fellow*) formerly Chief Aerodynamicist, Sir W. G. Armstrong Whitworth Aircraft Ltd., is now Head of the Astronautics Section, Hawker Siddeley Aviation Ltd.

Graham B. Hustings (*Associate Fellow*) formerly Section Leader, Design Office, Vickers-Armstrongs (Aircraft) Ltd., at Hurn Airport, is now Senior Designer.

Francis A. Kappey (*Associate Fellow*) formerly at the Birmingham Office, Ministry of Supply Inspection Division, has returned to Saunders-Roe Ltd., as Inspector in Charge, A.I.D., at Southampton Airport.

Lieut. Commander R. A. Langley (*Associate Fellow*) formerly Senior Engineer at the R.N. Air Station at Culdrose, is now on the Staff of Flag Officer Air (Home). (Correction to September Journal Notices.)

J. A. Lomax (*Graduate*) formerly with Avro Aircraft Ltd., Canada, is now with Pitney-Bowes Inc., Stanford, Connecticut, as a Machine Designer.

B. W. Martin (*Associate Fellow*) formerly a Lecturer in Mechanical Engineering, Kings College, Newcastle-upon-Tyne, has been appointed to the Readership in Applied Thermodynamics in the University of London at Imperial College of Science and Technology.

Eric Mensforth (*Fellow*), Chairman of Westland Aircraft Ltd., has been appointed Chairman of Saunders-Roe Ltd.

Peter Milns (*Graduate*) formerly a Structures Engineer, Cessna Aircraft Corp., is now with the Structural Dynamics Group, Boeing Airplane Company, Wichita.

Stanley L. Nayler (*Graduate*) formerly an Aerodynamicist, Avro Aircraft Ltd., Canada, has joined the Boeing Airplane Company, Washington, as an Aerodynamicist, Transport Division.

B. G. Newman (*Associate Fellow*) formerly Canadair Research Professor of Fluid Mechanics, Laval University, Quebec, has been appointed to the new Canadair Chair of Aerodynamics at McGill University, Montreal.

G. T. O'Brien (*Graduate*) formerly Systems Analyst, Avro Aircraft Ltd., Canada, is now on the Technical Staff, Radio Corporation of America, Missile Electronics and Controls Department, Burlington, Massachusetts.

A. M. Peduzzi (*Associate Fellow*) formerly with Fairchild Engine Division, New York, is now Head of Hypersonic and Advanced Ramjet Research, Bristol Siddeley Engines.

T. B. Saunders (*Graduate*) having completed the two-year Diploma Course at the College of Aeronautics at Cranfield, is now employed by Saunders-Roe Ltd.

D. N. Scard (*Associate Fellow*) formerly Chief Flight Test Engineer, Avro Aircraft Ltd., Canada, is now Assistant Chief Flight Development Engineer, A. V. Roe and Co. Ltd., Woodford Aerodrome.

John C. Scouller (*Graduate*) formerly with Blackburn Aircraft Ltd., is now an Engineer, Wind Tunnel Department, English Electric Aviation Ltd., Warton.

Flight Lt. B. D. Smith (*Associate Fellow*), formerly at the Armament Department, Royal Aircraft Establishment, has been posted to No. 3 Advanced Weapons Course, R.A.F. Technical College, Henlow.

S. A. Stephenson (*Associate Fellow*) formerly Chief Draughtsman has been appointed Assistant Manager of the Hull factory of The Imperial Typewriter Company.

Dr. G. A. Tokaty (*Associate Fellow*) formerly Reader at the Northampton College of Advanced Technology, London, is now Visiting Professor of Astronautics, University of Kansas, U.S.A.

Dennis J. Tyler (*Associate Fellow*) formerly Development Test Engineer, Megator Pumps and Compressors Ltd., is now Technical Representative in the London Region, J. W. Roberts Ltd., of Bolton, Lancashire.

Wing Commander P. S. V. Vallis (*Associate Fellow*) formerly in the Directorate of Aircraft Engineering, Air Ministry, is now Modifications Officer, Flight Refuelling Ltd., Blandford.

Wing Commander G. C. Wainwright (*Associate Fellow*) formerly with the Ballistic Missile Division, Guided Weapons Department, Royal Aircraft Establishment, has been appointed Chief Instructor, Weapons Systems Engineering Wing, Royal Air Force Technical College, Henlow.

Sqn. Ldr. R. J. E. Walker (*Associate Fellow*) formerly at the R.A.F. Technical College, Henlow, is now in the Directorate of Weapon Engineering, Air Ministry, Whitehall.

D. L. Hollis Williams (*Fellow*), Technical Director, Westland Aircraft Ltd., has been appointed to the Board of Saunders-Roe Ltd.

Group Captain D. W. Williams (*Associate Fellow*) formerly Station Commander, School of Technical Training, Melksham, Wilts., is now Command Engineering Officer at Headquarters, Fighter Command, R.A.F.

B. S. Wodhams (*Associate*) formerly with D. Napier and Son Ltd., is now with British Light Steel Pressings Ltd., of Acton.

Seventh Anglo-American Aeronautical Conference

About 75 members of the Society, a number of them accompanied by their wives, are attending the Seventh Anglo-American Aeronautical Conference in New York. The Conference will be opened with an informal reception on 4th October and after attending lecture sessions and discussions from 5th to 7th October the British delegates will make a number of visits to aircraft firms and research establishments in the Long Island, New Jersey and Cleveland areas before going to Toronto, by way of Niagara Falls. In Toronto delegates will visit the de Havilland Aircraft of Canada Ltd., and the Defence Research Medical Laboratories and will attend a dinner given by the Canadian Aeronautical Institute; the Conference will finish on 16th October at the University of Toronto Institute of Aerophysics Symposium and the opening of the new U.T.I.A. building.

The presentation of the Elmer A. Sperry Award for 1959 will be made at the Conference Dinner on 7th October. It has been awarded to the de Havilland Aircraft Co. Ltd., for their outstanding achievement in the field of transportation and to Sir Geoffrey de Havilland, for leadership as President of the Company, to Mr. C. C. Walker, as Technical Director and Chief Engineer and, in memoriam, to Major Frank Halford, as Chief Engineer and Technical Director of the de Havilland Engine Company Ltd.

The following papers will be given in New York:—

5th October

Instrumentation for Space Science Research. John W. Townsend, Jr. Assistant Director, Goddard Space Flight Center, N.A.S.A.

Aircraft Fatigue—A Survey of Current Thought. R. J. Atkinson, Head, Structural Fatigue Division, Structures Department, R.A.E.

Recent Studies of Satellite Orbits. E. C. Cornford, D. G. King-Hele and R. H. Merson, Guided Weapons Department, R.A.E.

A Study of the Stability and Control Characteristics of Atmospheric-Entry Type Aircraft Through Use of Piloted Flight Simulators. Brent Y. Creer, D. R. Heinle and Rodney C. Wingrove, Aeronautical Research Engineers, Ames Research Center, N.A.S.A.

The Caribou Utility STOL Aircraft. R. D. Hiscocks, de Havilland Aircraft of Canada, Ltd.

Engines for VTOL Aircraft. H. Pearson, Chief Research Engineer, Rolls-Royce Ltd.

6th October

The Behaviour of Supersonic Boundary Layers in the Presence of Shock Waves. G. E. Gadd and D. W. Holder, National Physical Laboratory.

Hypersonic Separated Flows. S. M. Bogdonoff, Professor of Aeronautical Engineering and Head, Gas Dynamics Laboratory; and Irwin E. Vas, Research Associate, James Forrestal Research Center, Princeton University.

Work of the Blind Landing Experimental Unit. W. J. Charnley, Superintendent, Blind Landing Experimental Unit, R.A.E.

Blind Landing and Take-Off Consideration for Present and Future Aircraft. Nelson C. Harnois, Division Engineer, Electronic and Armament Systems; and G. H. Stocker, Electronic Systems Engineer "A," Electronic and Armament Systems Engineering Department, Lockheed Aircraft Corporation.

Design Philosophy for High Acceleration and Temperature. Bernard O. Heath, Assistant Chief Engineer, English Electric Aviation, Ltd.

Interactions Between the External Flow and Rocket Exhaust Nozzle. Carl F. Schueller, Chief, Propulsion Aerodynamics Division, Lewis Research Center, N.A.S.A.

The Future of Automatic Control on Fixed Wing Aircraft. Professor G. A. Whitfield, College of Aeronautics, Cranfield.

Flying Qualities Associated with Several Types of Command Flight Control Systems. Sigurd A. Sjoberg, Aeronautical Research Engineer, Langley Research Center, N.A.S.A.

7th October

Re-entry Studies in Free-Flight Ranges. G. V. Bull, Superintendent, Aero Physics Wing, Canadian Armament Research and Development Establishment.

Ablation in Hypersonic Flows. Lester Lees, Professor of Aeronautics, Guggenheim Aeronautical Laboratory, California Institute of Technology.

Unresolved Civil Airworthiness Problems. Walter Tye, Chief Technical Officer, Air Registration Board.

Research and Development Programme for Future Air Traffic Control Systems. Captain Alden C. Packard, U.S.N., Acting Director of Research and Development, Federal Aviation Agency.

Some Considerations of Shape and Control for Hypersonic Flight. Hugh Metcalfe, Chief Aerodynamicist, Bristol Aircraft Ltd.

Therodynamics and Heat Flow Analysis by Lagrangian Methods. M. A. Biot, Research Consultant.

Similarity and Flight Simulation in Hypersonic Test Facilities. A. H. Flax, Vice-President, Technical Operations, Cornell Aeronautical Laboratories.

Copies of each paper will be available in the Library—for consultation only.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Arthur Daniel Button
Dennis Peter Du Plooy (*from Graduate*)
Robert Harold Ladd (*from Graduate*)
Peter Martin (*from Associate*)
James Stanford Plowman (*from Graduate*)
Ronald David John Powell
Clive Redmayne (*from Graduate*)
Hugh Strawson

Associates

Eric Peter Bedford
Cyril Victor George Mancey
Iain Edward Pickering
Malavi Narayan Ranganathan

Graduates

Trevor Arthur Field
John Brian Griffith
Hugh Rupert Hughes (*from Student*)
Laurence Herbert Pretty (*from Student*)

Students

Douglas William Beard
William Richard Harwood

Companion

Albert John Morris

Eleventh Conference of the British Occupational Hygiene Society

The Eleventh Conference of the British Occupational Hygiene Society will be devoted to problems of heating and ventilation as they affect personnel, and will be held on Thursday 5th November 1959 at the Institute of Mechanical Engineers, Birdcage Walk, S.W.1. Ventilation of military aircraft (from the physiological requirements and engineering aspects) will be among the subjects discussed.

Full details may be obtained from Dr. D. Turner, The Associated Ethyl Co. Ltd., Ellesmere Port, Cheshire.

LECTURE THEATRE APPEAL

The following lists show further donations received up to the time of going to press.

Donations	£	s.	d.	£	s.	d.
Previous total (including minor adjustments)				8134	8	7
R. C. Abel, Esq.	1	0	0			
D. J. Acklam, Esq.	2	2	0			
R. C. Aikman, Esq.		10	0			
Prof. L. Aitchison	2	2	0			
R. Ashton, Esq.	15	0	0			
J. A. Barnes, Esq.	2	0	0			
H. C. Barton, Esq.	2	0	0			
E. J. Baughen, Esq.	2	2	0			
R. A. Beaumont, Esq.	2	2	0			
W. O. Beer, Esq.	2	2	0			
Belfast Branch	34	0	0			
E. N. B. Bentley, Esq.	2	2	0			
A. A. Blythe, Esq.	1	1	0			
J. W. T. Brachett, Esq.	1	1	0			
E. Brelsford, Esq.	2	2	0			
R. A. C. Brie, Esq.	2	2	0			
British Overseas Airways Corporation	52	10	0			
Lt. Cdr. B. Bullivant	1	0	0			
Major F. A. Bumpus	10	10	0			
Sqn. Ldr. H. W. Busen-Schmitz	1	0	0			
A. C. Campbell-Orde, Esq.	5	0	0			
Flt. Lt. C. S. Carpenter	1	0	0			
Sqn. Ldr. R. L. Cater	5	0	0			
Lt. Cdr. W. E. Clarke	3	3	0			
A. N. Clifton, Esq.	5	0	0			
C. H. Colvin, Esq. (U.S.$100)	35	12	6			
J. V. Connolly, Esq.	10	13	0			
P. R. Connolly, Esq.	1	10	0			
Lt. Cdr. F. Cumberland	2	2	0			
J. P. Curry, Esq.	3	0	0			
G. R. Dawbarn, Esq.	5	0	0			
J. S. Dean, Esq.	1	4	0			
P. K. Digby, Esq.	1	0	0			
J. R. Dixon, Esq.	1	1	0			
F. H. East, Esq.	3	3	0			
A. G. Elliott, Esq.	10	10	0			
R. S. Emerson, Esq.	2	0	0			
E. M. O. Instrumentation Ltd.	5	5	0			
D. Eyre, Esq.	4	0	0			
Capt. T. H. Farnsworth	10	10	0			
G. H. A. Fenton, Esq.	2	2	0			
A. W. Furneaux, Esq.	1	0	0			
K. P. Gan, Esq.	3	0	0			
J. S. Gibbons, Esq.	5	0	0			
B. D. Gibbs, Esq.		7	6			
H. R. Gillman, Esq.	1	1	0			
E. T. Gleed, Esq.	3	0	0			
Wg. Cdr. H. F. Glover	2	2	0			
P. T. Griffith, Esq.	5	5	0			
L. D. Gurney, Esq.	2	2	0			
Lt. Col. R. K. S. Harker	1	1	0			
Sqn. Ldr. F. G. Harley	2	2	0			
Gp. Capt. E. A. Harrop	2	2	0			
Mrs. W. Hayward	1	1	0			
Sqn. Ldr. W. Heaton	2	2	0			
M. B. Howard, Esq.	1	0	0			
R. A. Howell, Esq.	1	0	0			
C. T. Huey, Esq.	5	0	0			
Flt. Lt. H. B. Iles	3	0	0			
E. C. Jackson, Esq.	1	1	0			
K. H. James, Esq.	2	2	0			
F. E. Jones, Esq.	10	10	0			
Gp. Capt. S. W. Lane	2	2	0			
Carl W. Lemmerman, Esq. (U.S.$100)	35	12	6			
Prof. K. L. C. Legg	10	10	0			
J. R. Lewin, Esq.	10	0	0			
W. H. Lewis, Esq.	2	2	0			
W. T. O. Lewis, Esq.	2	0	0			
London Airport Branch	16	0	0			
E. Loveless, Esq.	5	0	0			
A. C. Lovesey, Esq.	10	10	0			
Luton Branch	10	0	0			
A. H. Makomaski, Esq.	2	2	0			
Dr. E. H. Mansfield	5	0	0			
Wg. Cdr. W. R. J. Marriott	5	0	0			
M. G. Marsh, Esq.	2	2	0			
A. J. Mautner, Esq.	1	1	0			
Cdr. B. B. Mungo	5	0	0			
G. R. Nicolson, Esq.	2	0	0			
T. R. F. Nonweiler, Esq.	1	1	0			
G. W. Nunn, Esq.	2	2	0			
W. J. Peters, Esq.	3	0	0			
Preston Branch	25	0	0			
Prof. J. H. Preston	2	2	0			
J. H. Richardson, Esq.	2	2	0			
J. G. Roxburgh, Esq.	3	3	0			
Rubery Owen Group	50	0	0			
R. H. Satterford, Esq.	2	2	0			
W. W. D. Seymour, Esq.	1	1	0			
D. V. Shaw, Esq.	1	1	0			
Sqn. Ldr. A. E. Smith	3	3	0			
G. A. Smith, Esq.	2	2	0			
H. F. H. Smith, Esq.	1	1	0			
Sperry Gyroscope Co. Ltd.	250	0	0			
Lt. P. M. G. Spence, R.N.	1	1	0			
A. Symon, Esq.	3	3	0			
Flt. Lt. A. B. Thompson (additional)	1	0	0			
Flt. Lt. J. W. Titterton	2	2	0			
P. J. Treweek, Esq.	2	2	0			
S. E. Tweedy, Esq.	3	3	0			
Sir Reginald Verdon Smith	50	0	0			
Wg. Cdr. W. T. Wakeham	2	2	0			
J. E. Walker, Esq.	2	2	0			
Weybridge Branch (additional)	4	1	6			
Gp. Capt. E. A. Whiteley	5	5	0			
A. Whitfield, Esq.	6	6	0			
D. C. Whittley (Can.$10)	3	13	8			
A. J. Willmore, Esq.	2	2	0			
A. Woodward-Nutt, Esq.	5	5	0			
P. M. Wright, Esq.	1	1	0			
	880	12	8			
				9015	1	3

7 Year Covenants						
Previous total (including minor adjustments)				2524	17	5
N. Albion, Esq.	1	0	0			
G. E. Archdale, Esq.		10	0			
L. L. Bridgman, Esq.	2	2	0			
D. G. Brown, Esq.	2	2	0			
A. A. Butler, Esq.	1	0	0			
K. F. S. Chard, Esq.	1	0	0			
J. C. Cooper, Esq.		10	0			
R. P. Dickinson, Esq.	1	0	0			
Air Cdr. W. D. Disbrey	1	0	0			
Flt. Lt. D. E. Dormer	1	0	0			
Dowty Group Ltd.	218	14	2			
R. G. Evans, Esq.	1	1	0			
Sqn. Ldr. D. J. Flood	2	2	0			
J. F. Foss, Esq.	1	6	3			
J. Hale, Esq.		10	0			
Dr. G. J. Hancock	1	1	0			
R. G. Harmer, Esq.	1	0	0			
R. H. T. Harper, Esq.	2	0	0			
R. G. Hoare, Esq.	1	0	0			
P. C. Holdorf, Esq.	1	0	0			
D. James, Esq.	2	0	0			
L. J. Jelonek, Esq.	1	0	0			
D. A. Lessware, Esq.		10	6			
D. F. McGregor, Esq.	1	0	0			
H. S. Mettam, Esq.	2	0	0			
C. W. Nicholas, Esq.		10	6			
J. A. P. Nidd, Esq.	1	0	0			
J. D. Pearson, Esq.	10	10	0			
B. R. Perkin, Esq.	1	1	0			
S. G. Pountain, Esq.	1	0	0			
W. S. Rope, Esq.	3	0	0			
A. A. Rubbra, Esq.	3	3	0			

	£	s.	d.	£	s.	d.
J. Slatford, Esq.	1	0	0			
A. I. Stevenson, Esq.	1	0	0			
J. C. Stevenson, Esq.	2	2	0			
Flt. Lt. E. S. Street	1	0	0			
Wg. Cdr. G. R. Stroud	1	0	0			
M. K. Than, Esq. (2nd Covenant)	1	0	0			
E. J. D. Townesend, Esq. ...	1	1	0			
D. I. Vickery, Esq.	1	1	0			
R. H. Walmsley, Esq.	10	0	0			
J. D. Watkins, Esq.	1	0	0			
L. R. Webb, Esq.	1	0	0			
D. E. Weeding, Esq.	2	2	0			
Dr. H. M. Wilson	2	0	0			
	292	19	5			
				*£2817	16	10

GRAND TOTAL **£51,300 (approx.)**

(allowing for recovery of Income Tax at present Standard Rate on 7 and 10 year convenants)

Promises amounting to a further £31,266 had been received up to the time of going to press.

Donations in kind have been promised by the following firms since the last list was published:

Tube Investments (Pel Ltd.)—Seating

The Wallpamur Co. Ltd.—Paint

Jablo Propellers Ltd. and B. Jablonsky, Esq.—Acoustic Lining Material.

**With Income Tax at the present standard rate of 7s. 9d. in the £ this figure should produce £32,204 (approx.) over the 7-year period.*

10 Year Covenant

Previous total					†£612	10 0

†With Income Tax at the present standard rate of 7s. 9d. in the £ this figure should produce £10,000 over the 10-year period.

Bankers Orders for Annual Payments

Previous total	61	4	0
H. C. Bevis, Esq.	1	0	0
R. A. Frazer, Esq.	2	2	0
V. Hudson, Esq.	1	0	0
D. C. Smith, Esq.	5	0	0
G. H. Vosper, Esq.	1	1	0
	£71	7	0

The following have also subscribed but do not wish the amounts of their contributions to be published; the total is, however, included in the Grand Total of £51,300 shown above:

E. C. Blackman, Esq.	Air Cdre. L. P. Moore
A. A. Clark, Esq.	D. Pierrepont, Esq.
P. Cowley, Esq.	D. M. Puddephatt, Esq.
A. W. Crichton, Esq.	R. S. Randall, Esq.
G. E. Davies, Esq.	P. L. Sutcliffe, Esq.
P. G. Edgington, Esq.	A. Syme, Esq.
C. D. Holland, Esq.	J. C. Wallin, Esq.
A. W. E. Houghton, Esq.	R. S. Ward, Esq.
D. H. Howle, Esq.	Q. Wilson, Esq.
C. G. Longford, Esq.	J. A. B. Wolfe, Esq.
B. W. Loughridge, Esq.	H. F. Young, Esq.

Training Center for Experimental Aerodynamics

From October 1959 the Training Center for Experimental Aerodynamics (T.C.E.A.), at Rhode-Saint-Genève, is to be supported financially on a multi-lateral basis by the nations of NATO who expect to have students qualified to attend the course of instruction. T.C.E.A. will continue its present close association with the NATO Advisory Group for Aeronautical Research and Development.

Founded in 1956, T.C.E.A. has hitherto been financed jointly by Belgium and the United States of America. Forty-five students from 11 NATO countries have obtained Diplomas during the past three years, including seven from the United Kingdom.

Symposium on Aerodynamic Capture of Particles

A Symposium on Aerodynamic Capture of Particles will be held at the Research Station of the British Coal Utilisation Research Association, Randalls Road, Leatherhead, Surrey, on 13th and 14th January 1960.

The subjects covered will be:—collision of particles with obstacle or collector; coagulation in turbulent flow; wash-out and collision with raindrops; and collision of charged particles. The proceedings of the symposium will be published by Pergamon Press Ltd.

The fee for the symposium is one guinea. Application forms and further information may be obtained from B. B. Morgan, Esq., Local Secretary, Physics Department, at the address given above.

Acknowledgment

The Council wishes to thank Lieut. Cdr. C. H. H. Owen, R.N. of 41a Roland Gardens, London, S.W.7, for an album of aeronautical postcards c.1911, including several bearing the commemorative stamp of the Circuit Européen d'Aviation, June 1911. This presentation is an outstanding instance of somebody (unconnected with the Society) clearing out old papers and exercising some thought instead of using the dust-bin.

"Aircraft Engineering"

Members may be interested to know that the first eighteen volumes of *Aircraft Engineering* (1929-1946) are now available in reprint form from Wm. Dawson and Sons Ltd., 16 West Street, Farnham, Surrey. The price is £6 10s. 0d. per volume, cloth bound.

Aircraft Gas Turbine Theory and Design

A short course on Aircraft Gas Turbine Theory and Design will be held at the College of Aeronautics from 2nd to 20th November 1959.

The course will deal mainly with performance, systems, turbo-machine aerodynamics and related design topics, but will include some experimental work on engines. The fee is £70 inclusive of full board and residence.

Further details and copies of the syllabus may be obtained from The Warden, College of Aeronautics, Cranfield, Bletchley, Bucks.

Journal Binding

Permanent Binding

1958 Volume (including packing and postage *in the United Kingdom*) .. .. .. £1 4s. 0d.

Previous Volumes (including packing and postage *in the United Kingdom*) .. .. £1 6s. 0d.

Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Members are asked to be certain that the address to which they want their Journals sent is the same on their letters to the Lewes Press and to the Society.

Self-Binder Cases

Self-Binder cases of the "Easibind" type to hold 12 Journals are available from the Offices of the Society at 13s. 6d. each (including postage *in the United Kingdom*).

Summaries of Lectures

Main Lecture to be given on 27th October 1959

AIRCRAFT FATIGUE—A SURVEY OF CURRENT THOUGHT

by

R. J. ATKINSON, B.E., D.I.C., F.R.Ae.S.
(Structures Department, R.A.E.)

Structural fatigue has been a major issue in design and operations of aircraft for more than a decade. It is proposed to assess what has been done and where we ought to go in the light of experience and thought in the U.K. All types of operational flying are considered except those with significant kinetic heating.

It is suggested that the first objective, safety, has now largely been achieved. The most important contribution to this achievement is the general awareness of design teams that fatigue is a vital consideration, and the universal acceptance of the need for rigorous and systematic design procedures.

The next concern is efficiency; the main effort is needed in the laboratory and in the correlation of laboratory data with service experience.

The presentation is under the heading of design procedure, design requirement, loading actions, fatigue data, assessment of fatigue performance and proving. The illustrations are from work in the U.K., but the opinions are based on data from many countries.

NOTE—This Lecture is a repeat of the paper given by Mr. Atkinson at the Seventh Anglo-American Aeronautical Conference in New York this month and will be published in the Conference Proceedings.

Man Powered Aircraft Group—Inaugural Meeting on 30th October

The inaugural meeting of the Man Powered Aircraft Group of the Royal Aeronautical Society will take place at 7 p.m. in the Library at 4 Hamilton Place on Friday 30th October 1959. The President of the Society will take the Chair.

The lecture will take the form of a resumé of the theory and practice of flight by man power, with a number of members of the Group available to initiate discussion and answer questions on various technical aspects of the subject. The meeting will be opened with a short historical survey by Mr. H. B. Irving, O.B.E., Chairman of the Steering Committee of the Group. This will include an account of man's attempts to achieve muscle flight up to the present time, a discussion of the reasons which have induced men to make these attempts and of the benefits likely to accrue to human knowledge from them, and a mention of the work at present being done in this country and elsewhere.

The other members of the Group who will be on the platform will be:—

1. Dr. D. R. Wilkie of University College, London, who is an expert on the physiological phenomena associated with animal flight.
2. Mr. T. R. F. Nonweiler who is an aerodynamicist at Queen's University, Belfast, and has recently completed a design study for a two-man-powered aircraft.
3. Mr. B. S. Shenstone, Chief Engineer B.E.A., who has for many years interested himself in the engineering problems associated with flight by man power.

It is hoped that this arrangement will lead to a lively discussion and that the interest of members of the Society will be stimulated in the other lectures being arranged by the Group during the coming season.

The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 63 OCTOBER 1959 NUMBER 586

Thrust Reversal for Jet Aircraft*

by

R. H. COLLEY, B.Sc., A.F.R.Ae.S.

(Assistant Chief Designer, Rolls-Royce Ltd.)

1. Summary

Several years ago it became apparent that there was a need for some means of reversing the thrust of jet engines on landing—the equivalent of reversing pitch propellers on piston and turbo-prop engines.

Many different designs were investigated on the drawing-board, with experimental backing in some cases, and when the best configurations had crystallised detail work started on a reverser for the Avon engine. While this was being developed a second design, identical in its main principle but different in many small ways, was prepared for the Conway engine.

Basically the reverser consists of a box structure which replaces a portion of the jet pipe, containing in two opposite walls outlet ports with vanes to direct the gas partially forwards, and with a pair of internal doors which alternatively close the outlet ports (allowing the gas to flow freely straight through the box to the jet pipe nozzle for forward thrust), or close the back end of the box leaving the side ports open (to direct the gas out and forwards to give reverse thrust).

There is no lubrication system, all main pivots being specially developed roller bearings running hot and dry, and the seals for the doors are all metal.

Pneumatic rams are used to operate the reverser and selection is performed by the pilot through a mechanical system. Special attention has been paid to making the system as safe and foolproof as possible.

A considerable amount of experimental work has been carried out; rig testing to develop bearings, rams and control gear, model testing for air flow and temperature study, engine testing for further confirmation of the same things, in addition to mechanical development and performance checks and, of course, flight testing to complete the job.

2. The Case for a Thrust Reverser

The continually increasing speeds which characterise each new generation of aircraft, both in the transport and military fields, lead to increases of wing-loading and consequently to faster take-off and landing speeds. Engine power too must go up in step, and this provides the improved thrust necessary to accelerate the aircraft to take-off speed without prohibitive runway lengths.

Clearly there is a parallel requirement to improve deceleration after landing for the same consideration of runway length. Originally rolling resistance plus the aerodynamic drag of the aircraft (including the propellers) was more than sufficient; next, wheel-brakes were introduced, but since these are of no great value on icebound, or even wet, runways the reversible pitch propeller came along. Then with the jet engine there was no longer a propeller which would provide drag and which could be reversed. Tail parachutes were introduced and have served moderately well for military aircraft but are inconvenient for civil use.

The upper half of Fig. 1 shows calculated landing run distances for a hypothetical four-engined aircraft on wet and icebound runways. The figures represent the rolling distances only from the actual touch-down point (at 120 knots) until coming to rest. With safety margins and allowances for clearing obstacles on the approach the actual runway lengths would have to be appreciably more and are clearly becoming excessive. The calculations allow for aerodynamic drag, rolling resistance and brakes (improving as the lift decays and puts more weight on to the wheels) and assumes that two engines have to be kept running at flight idle speed (giving forward thrust) to maintain auxiliary services.

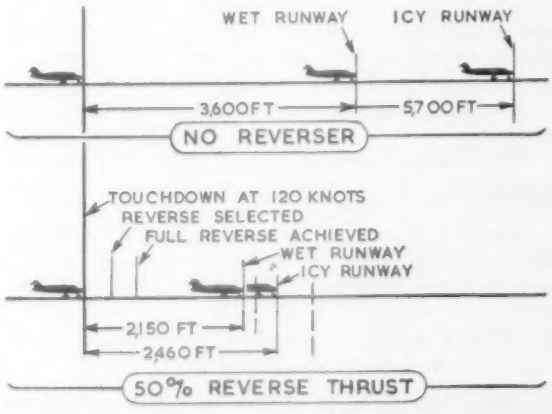

FIGURE 1. Comparative landing runs on a hypothetical 200,000 lb. aircraft with four Conway engines.

*Based on a lecture given before the Derby Branch of the Society on 1st December 1958.

Assuming that each engine is fitted with a device enabling it to give a reverse thrust equivalent to 50 per cent of its take-off thrust (a figure which is reasonably attainable in practice) the figures shown in the lower part of the diagram can be achieved. These can be seen to be very considerable improvements.

The two dotted lines show the small increases of landing run should it be necessary to shut down two of the engines at 60 knots.

Although no attempt has been made to prepare a similar diagram for take-off it is clear that in the event of the pilot having to abandon take-off part way down the runway, similar savings in stopping distance are available.

3. Requirements of a Thrust Reverser

Safety considerations dictate, first and foremost, that the reverser must not be capable of operating at the wrong time. Multi-engined aircraft are designed so that loss of thrust of one engine can be safely tolerated at any point during take-off. However, should one engine suddenly change its thrust from forward to reverse, then this is equivalent to losing the thrust of one and a half engines, which obviously cannot be accepted. To this end it is necessary that:—

(*i*) The pilot's lever system is such that inadvertent selection of reverse thrust during take-off is impossible.

(*ii*) No single failure in the operating system shall select reverse thrust.

(*iii*) The primary thrust-changing elements must be inherently biased away from the reverse thrust position.

The engine requires that the fitting of a reverser should not affect its normal working conditions, and that no appreciable loss of thrust or fuel economy during flight is caused. In reverse thrust the device should not cause debris or excessive amounts of hot air to enter the engine intake.

The aircraft requires that the discharge of hot gas in reverse thrust should not impinge on to parts of the aircraft; nacelles, wing, landing gear and tyres, cabin windows and landing flaps, for instance, have all to be considered. As well as causing over-heating, it has been found that such impingement can cause structural damage due to the vibration imposed by turbulence in the gas stream.

Weight, cost and complication must be kept to a minimum.

Fire hazards, such as could be caused by the introduction of lubrication or hydraulic systems adjacent to the jet pipe, must be avoided.

Finally it is necessary that, when required, a reasonable amount of thrust (in the region of 50 per cent of take-off thrust) should be rapidly and reliably available.

4. The Choice of the Basic Rolls-Royce Reverser Design

Many configurations have been investigated on paper, some in considerable detail. A selection of four different types is shown on Fig. 2 to illustrate some of the arrangements considered, and the reasons for discarding them.

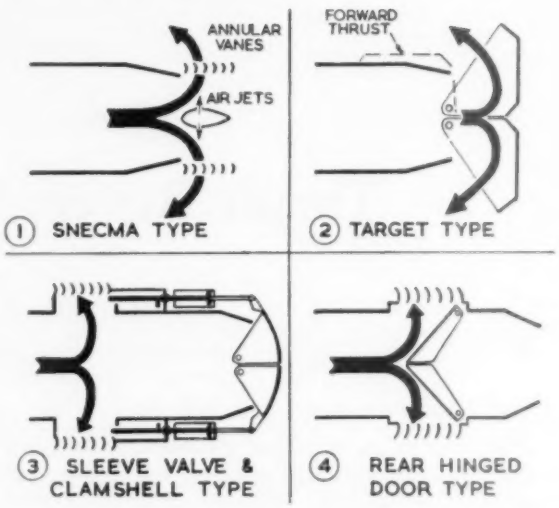

FIGURE 2. Early reverser projects.

The SNECMA type is of French origin and involves a set of annular vanes around the efflux from the jet pipe. A small chamber carried behind the jet pipe on struts is provided with small nozzles from which compressed air can be directed to encourage the main exhaust from the engine to deflect outwards until it contacts the annular vanes and it is then drawn round in them and ejected partially forwards. Unfortunately this arrangement only works at relatively low pressure ratios and was found to give quite a low value of reverse thrust. It was decided, therefore, that the gas had to be more positively turned and the target type was considered. This, like the SNECMA device, had the advantage that it did not affect the jet pipe nozzle and that no positive seals were required. It was felt, however, that the construction would have to be very heavy to withstand the battering which it would suffer in the severe turbulence present in the jet pipe efflux.

A further disadvantage in an application such as the Comet 4 would be that the lower outlet would blow straight forwards onto the wing landing flaps and would obviously damage them. This landing flap in fact was the reason for moving the outlet from the back end of the jet pipe to a position part way along and the sleeve valve type was the first attempt at doing this. The sleeve valve surrounding the jet pipe could be moved axially by pneumatic rams to uncover the reverse outlets, while rods protruding from the other ends of the rams would operate clam-shells to cover the rear end of the jet pipe. There were two principal difficulties with this design, the first being the complication due to the two sets of mechanism, one for the outlets and one for the closure of the normal jet pipe nozzle, and the other being that interest was at this time being taken in noise suppressors so it was obviously desirable to keep the final nozzle clear of any mechanism to leave the way open for whatever shape of noise suppressor was

ultimately decided on. This lead to the fourth type, wherein the controlling doors were pivoted at the back edges as shown, so that they simultaneously closed the tail pipe and opened the reverser outlets.

This last type was taken to the stage of building a full-sized unit (using a heavy and simple construction) for a Derwent engine. In running this on the test-bed, and mounted in place of the rear section of a Meteor nacelle, the following were learned:—

(*i*) The approximate relationship between the actual reverse outlet area, and the equivalent jet pipe nozzle area to give the same engine operating condition.

(*ii*) That if the gas is turned too sharply forward (at say 30° to the engine axis) the gas would cling to the nacelle surface and over-heat it. At an angle of 45°, however, the gas discharged clear of the nacelle.

(*iii*) That owing to the offset between the door pivots and the centre of gas pressure, the operating loads were very high.

It was also clear that the box was bound to be heavy because of its flat sides—a bad shape for containing gas pressure.

Therefore, the arrangement sketched in Fig. 3 was finally adopted. This shows how the hinge point of the doors was moved to the centre of the jet pipe so that the main gas load was in line with the hinge, so reducing the operating loads. This kind of door had the additional advantage that it would swing in a circular box, so alleviating the structural problem of the earlier type. For clarity the diagram shows the reverser in a position where it is just beginning to move from forward to reverse thrust. As can be seen it consists of a box which forms the structure and contains the swinging eyelids. These, of course, have to be mounted on bearings and provided with seals to avoid leakage from the jet pipe during normal flight. Outlet vanes are necessary to direct the gas forward during thrust reversal and, in order to operate the reverser, some form of rams must be provided together with a suitable control system.

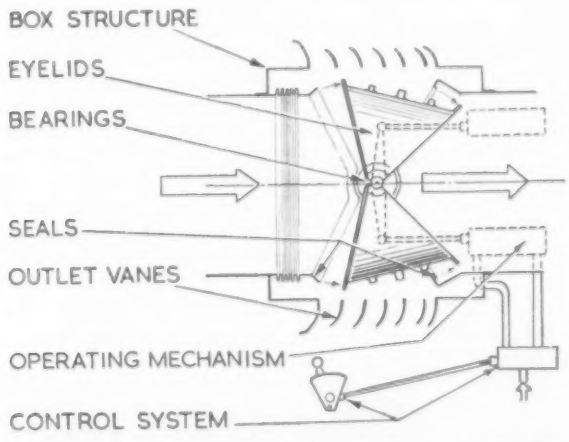

FIGURE 3. Principal elements of Rolls-Royce thrust reverser.

5. The Detail Design Problem

Naturally, each of the elements referred to above and indicated on Fig. 3, presented design problems, some of the main ones, with the solutions adopted, being as follows.

5.1. THE BOX STRUCTURE

This, the main carcase of the reverser, has to contain the gas pressure, hold the bearings (subject to a total load of 4 or 5 tons in the case of the Avon unit) and support the outlet vanes (imposing a further load of over 2 tons). The problem was how to construct it without undue weight.

A fabrication welded from Nimonic pressings was adopted. The main structural parts are the two deep section rings at each end joined by the box-section members along the sides of the outlet ports. These box sections support the tensile stress in the main skin which is under normal boiler hoop loads. They are referred to on Fig. 4 as torsion boxes. This is because the reverser walls are brought to as small a diameter as possible in order to reduce their weight and to give the maximum external space for the operating mechanism, and the tension load is, therefore, imposed tangentially on the box member putting a torsion couple on to it.

5.2. THE OUTLET VANES

These fit into the ports in the box structure, as indicated in Fig. 4.

Originally hollow aerofoil section vanes welded from sheet spanned the ports, attached at their ends and at four intermediate points to longitudinal tie-bars.

However, the sudden expansion as reverse thrust was brought into action caused the vanes to buckle and crack away from the tie-bars, so a staggered vane arrangement as shown on Fig. 5 was adopted, using single skin vanes made of thick sheet, rounded at the leading edge and tapered at the trailing edge.

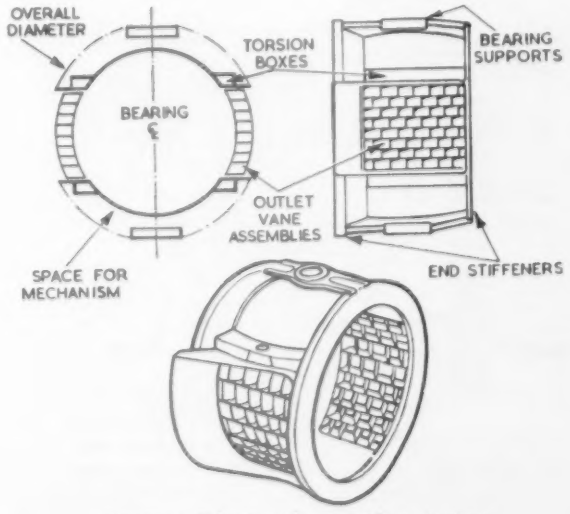

FIGURE 4. Diagram of reverser box structure.

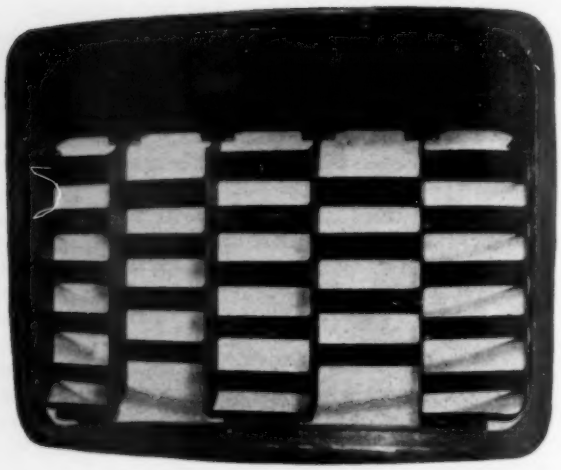

FIGURE 5. Outlet vane construction.

Expansion of the vanes is permitted by slight waving of the support beams, and these in turn are free to expand due to the link attachment at the rear end (*see* Fig. 6).

5.3. THE REVERSER DOORS AND SEALS

Figure 6 also shows the construction of the eyelids themselves and their seals. The eyelids are basically of single skin construction in order to avoid the distortion due to differential expansion experienced when a multi-skin construction is used in such a position with hot gases on one side of the structure. The stiffeners which are necessary to stiffen the assembly are of hollow section and are positively heated by allowing a constant flow of exhaust gas to circulate through them and leak overboard through the outlet vanes. Faces on the front and back edges of the doors butt against sealing edges carried in the box structure. It will be seen that the forward seal is mounted on a bellows which is intended to give the seal a certain amount of fore and aft resilience to accommodate relative expansion between the inner members of the reverser and the outer structure.

The sealing edges were initially of braided Inconel which was found to bed quite well against the faces on the eyelids but which permitted leakage between the strands of the wire forming the braid. An attempt to use solid seals was made initially by removing the braid from its channels and substituting copper strips which were hand-fitted to the eyelids. This gave an immediate improvement and was followed up by deleting the channels for the sealing material altogether and simply hand-fitting steel edges. Subsequently it has been found possible to machine these edges to sufficient accuracy to give satisfactory sealing and this is being adopted on production.

Figure 7 shows general views of the eyelid and among the features which can be seen are the air holes through which the circulating air flows to heat the box stiffeners, the sealing lands on the front and rear edges of the eyelid, the forgings by which the eyelids are bolted to flanges on the bearing spindles, and the sockets which receive the ends of the operating levers.

5.4. THE BEARINGS

As shown in Figs. 6 and 7, the eyelids are bolted to half flanges of a pair of co-axial spindles which are carried in bearings. These bearings provided what was perhaps the most difficult problem of all in the design of the thrust reverser.

Two distinct alternatives presented themselves; either orthodox bearings could be used, necessitating a lubrication system and in turn a cooling system to keep the temperature down to that at which lubrication is satisfactory, or bearings might be devised which would work without any lubrication or cooling at a temperature of something like 600°C.

To avoid excessive complication it was decided to make the attempt to use dry bearings and a rig was

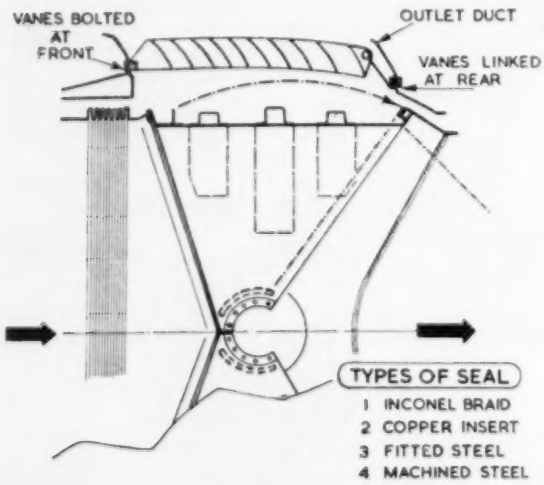

FIGURE 6. Diagram of eyelid seals.

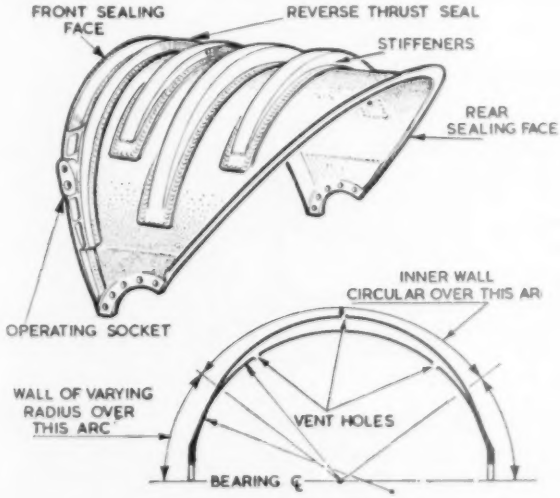

FIGURE 7. Reverser doors.

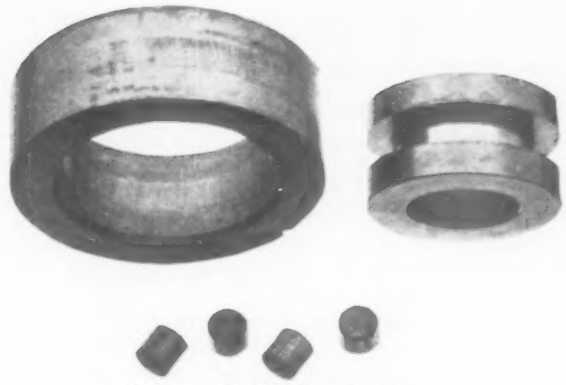

FIGURE 8. Bearing after rig test.

constructed to carry out tests on a variety of bearings. The basis of the rig was a spindle carried in a pair of substantial roller bearings. The spindle could be oscillated through about 60° by a lever mounted at one end, driven by a pneumatic ram. The other end projected into a lagged box and carried the inner race of the test bearing. The outer (stationary) race could be loaded pneumatically, and the box heated as required.

Although quite satisfactory results were obtained with plain bearings, friction was invariably high so efforts were concentrated on roller bearings.

Figure 8 shows a typical rig bearing including a few of its rollers after a satisfactory test. It had been run hot for nearly 6,000 operations under loads of up to 2,000 pounds and at the end of this test the diametral wear was less than one tenth of one thousandth and the friction had, in fact, gone down by about 20 per cent during the test. This bearing, which forms the basis of those subsequently designed in the reverser, was made of Nimonic material with a Stellite coating in the races and with tool steel rollers. The races were run full of rollers without cages.

Figure 9 shows a typical assembly of bearings as used in the Avon reverser. The two eyelids are carried respectively on part flanges on two concentric shafts, one running in two bearings in the casing and the other running in bearings within the first shaft. The operating torque to swing the eyelids is not transmitted by these actual shafts because the bolted joint between the eyelid and the flange was already highly stressed, due to the gas loads alone. Therefore, two further concentric sleeves were introduced around the main ones, each carrying an internal lever engaging with the sockets on the eyelid and an external lever coupled to the ram. These sleeves have piston ring seals where they pass through the main bearing plate which forms part of the pressure wall of the reverser.

5.5. PNEUMATIC RAMS AND LINKAGE

As shown on Fig. 10, the main feature of the linkage is the variable leverage introduced into it half way along, so that in forward thrust the rams work through a favourable leverage in order to supply a high load to the eyelid seals, even when the aircraft is cruising at high altitude, with relatively low pressure available at

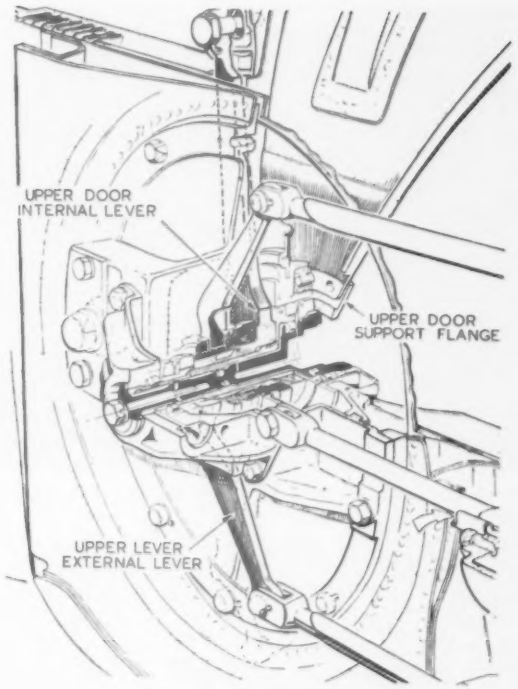

FIGURE 9. Reverser bearing.

the rams. The leverage changes as the ram approaches the reverse thrust position in order to economise on stroke of the ram.

Figure 11 shows diagrammatically the internal construction of the rams. It was decided to avoid the use of hydraulics because of the risk of fire in the event of leakage, and instead, to adopt a general construction similar to that already employed on re-heat systems, using air tapped from the engine compressor as the motive force. The ram was designed and manufactured

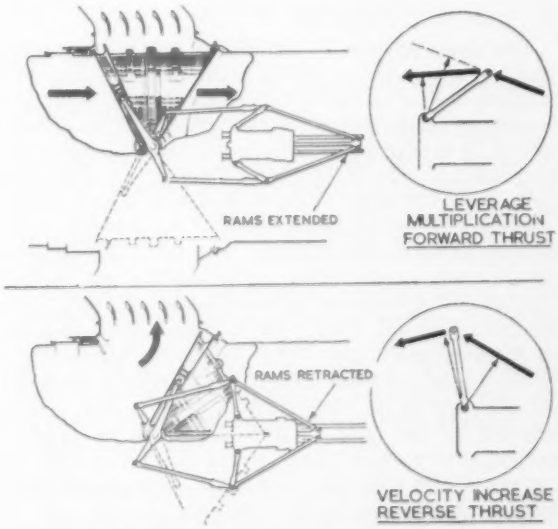

FIGURE 10. Thrust reverser lever system.

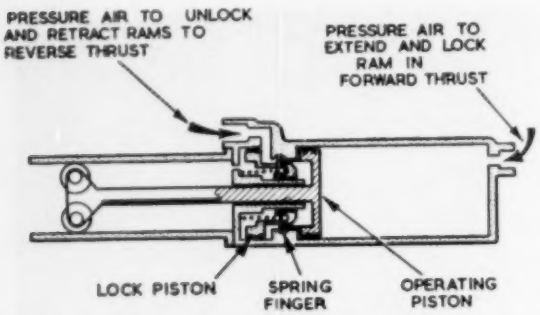
PRESSURE AIR TO UNLOCK AND RETRACT RAMS TO REVERSE THRUST
PRESSURE AIR TO EXTEND AND LOCK RAM IN FORWARD THRUST
LOCK PISTON
SPRING FINGER
OPERATING PISTON

FIGURE 11. Diagram of operating ram (Avon reverser).

by Dunlop who have introduced a carbon main bush which gives the complete support to the piston end of the rod, avoiding metallic contact between the piston and the cylinder wall. Sealing is done by piston rings which are again of carbon, so eliminating the need for lubrication. A feature which can be seen on the diagram is a safety lock in the form of spring fingers having projections which engage in a groove in the body of the ram. Before the ram can move from the forward position, in which it is shown on the diagram, these fingers have to spring inwards. This is normally prevented by an extension on a second piston which is spring-loaded to the right, as shown. In the event of any loss of air pressure during flight, therefore, the ram is mechanically held in the forward thrust position and there is no danger of normal thrust being lost, although backlash might cause an increase in leakage and a drop in efficiency of the engine. As soon as the supply of air is transferred to the left hand end of the ram, however, when reverse thrust is called for, this supply first moves the locking piston out of the way and so permits the main piston to move over and operate the reverser. The crosshead shown on the left is to ensure that the two eyelids of the reverser are synchronised in their motion.

5.6. THE SELECTOR VALVE

The main portion of the selector valve shown on Fig. 12 is similar in conception to the ram itself, in that the piston rod is carried in a long carbon bush and the two pistons which control the flow of air to select either forward or reverse thrust carry carbon piston rings. In order that the ends of these rings shall not catch in the ports, these are made small in size and consist of a double row of drillings in the wall of the cylinder with collector muffs on the outside. The air is fed to the selector valve via a reducing valve which is set, in the case of the Comet, to approximately 60 p.s.i. A protective blow-off valve is set a little higher in case the reducing valve jams. The reason for this is that the size of the rams was fixed to ensure enough force to seal the eyelids at high altitude cruise. The force provided by the rams at take-off, where the supply pressure is very much higher, would be great enough to over-stress the rods and levers if such a pressure limitation were not applied.

A further feature of the selector valve is a detent

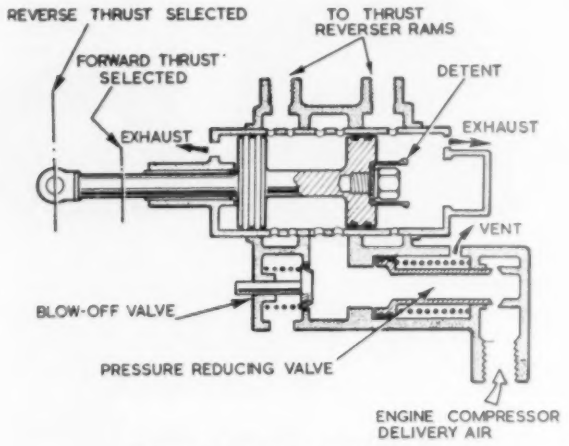

FIGURE 12. Diagram of selector valve.

consisting of projections on the ends of spring fingers, which when in forward thrust engage an internal rim at the end of the body to prevent the valve being shaken away from the forward thrust position should something come adrift in the linkage that operates it.

5.7. THE CONTROL SYSTEM

In considering the method by which the pilot controls the reverser four safety requirements were kept in mind:—

1. By far the most important thing was that no single failure must cause inadvertent selection of reverse thrust. This is particularly important during the take-off, and this is catered for by the mechanical lock already referred to in the ram, by the detent in the control valve, and by having mechanical as opposed to, say, electrical, operation between the pilot's control and the selector valve.

2. There must be no possibility of inadvertent selection due to pilot's error and Fig. 13 shows two arrangements of control console arranged with this in mind. On the Comet the two outboard throttle levers, controlling the two engines which are provided with

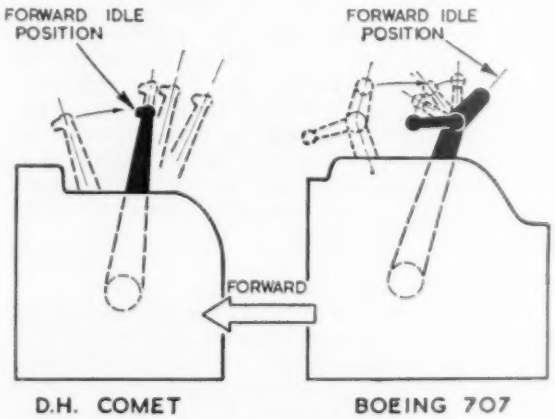

FIGURE 13. Diagrams of throttle stands.

thrust reversers, have their top handles so arranged that they can be easily lifted when at flight idle into reverse selection position. An additional lever, not shown on the diagram, must first be operated to unlock the lifting of the lever and it is this second lever which prevents premature selection if, for instance, the aeroplane lurches on the approach to land, causing the pilot to put an upward force on the throttles.

For the Boeing aircraft each of the four main throttle levers is provided with a subsidiary lever which is only in convenient reach of the pilot when the main levers are at idle and which, in any event, are interlocked so that they cannot be lifted until the main levers are at idle.

3. When the pilot has once called for reverse thrust it must not be possible through failure of the operation of the reverser for the engines to accelerate and give him forward thrust. Therefore, on both the aircraft referred to, a baulking stop is provided in the control system to prevent acceleration of the engines in reverse thrust and this stop is only withdrawn by the action of the reverser itself when it has operated.

4. Reverse thrust should obviously be available when called for and it was considered that the best way to achieve this was to use a mechanical control system as being inherently more reliable than, say, an electric or hydraulic system.

Developing the control system has been a major job in itself; in the initial flight tests of an Avon reverser (in a Hunter aircraft) the control system consisted of no more than a switch in the cockpit and a solenoid valve on the reverser. The Comet and Boeing 707/420 installations, however, include all the aforementioned safety features.

5.8. INSTALLATIONAL FEATURES

The mounting of the reverser is largely dependent on the general arrangement of the aircraft.

In the Avon unit as installed in the Comet (*see* Fig. 14) the engines fully occupy the space between the front and rear wing spars, therefore, it is necessary to mount the reverser separately from the engine behind the aft spar, and couple it to the engine by means of a floating section of jet pipe.

Two main mounting points are provided adjacent to, and in the same forgings as, the bearings, with a stabilising point near the upper outlet vane anchorages.

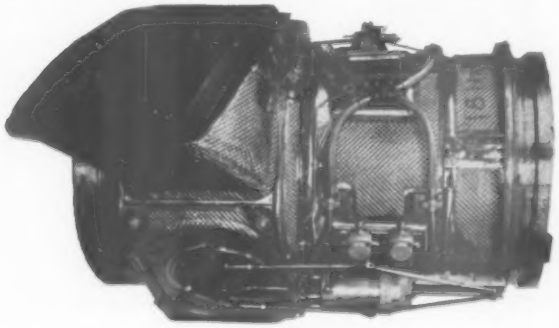

FIGURE 14. Avon reverser.

FIGURE 15. Conway reverser and noise suppressor.

Figure 14 also shows the thermal insulation blankets which protect the surrounding aircraft structure from radiation, ducts which lead the efflux to ports flush with the nacelle surface, pick-up points near the top for the ram air pipes, and two separate switches which respectively operate the throttle baulk withdrawal and the position indicator lights.

The Conway reverser was designed for a pod installation and, therefore, bolts directly to the back of the engine by-pass duct which was specially modified to carry the weight of the reverser and silencer. This unit is shown on Fig. 15.

6. Summary of Testing

It is not possible in a general paper such as this to do more than touch briefly on the enormous amount of test-work undertaken; the following summary can, therefore, do no more than give a broad idea of the several phases of development carried out.

6.1. RIG TESTS

Rig testing has been in progress ever since the project design period.

The bearing rig has already been mentioned (Section 5.4). A considerable amount of rig testing has also been done on individual rams, control valves and other items, and an elaborate rig simulated the complete control and ram system for the Conway reverser.

On this rig the full system, including baulks, locks, nacelle door operation (which was allowed for in the design) with sequencing system, was tested at the correct loads, ambient temperatures and vibration conditions, and several snags were unearthed and corrected before assembly of the first reverser was completed.

6.2. MODEL TESTS

To study the behaviour of the air inside the reverser box, a water rig was used. A scale model of the

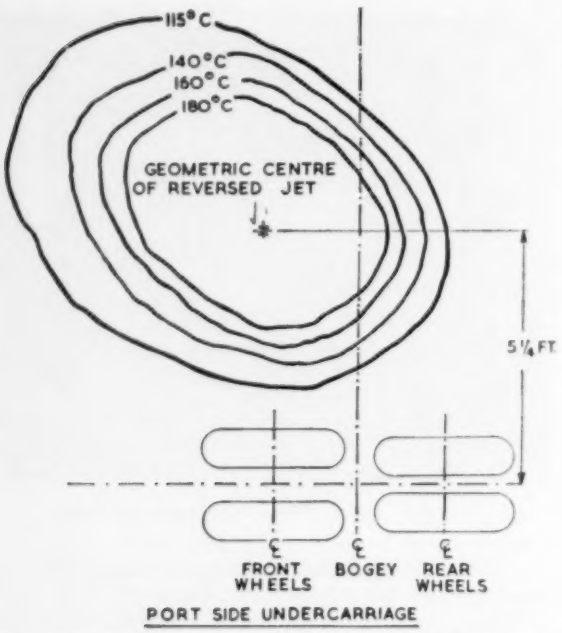

FIGURE 16. Comet with thrust reverser. Ground level temperature plot (aircraft static).

reverser—in reverse thrust position—was made in Perspex and in the usual fashion water containing air bubbles was flowed through.

This testing showed, for instance, that a mysterious cyclic change of effective nozzle area was due to an unstable lateral vortex caused by the sudden change of direction of the gas past the forward seal and out to the front outlet vanes.

Wind tunnel tests of half-models of both Avon- and Conway-engined aircraft were made, using hot air and steam to study the air flow outside the reverser.

It was necessary to establish at quite an early stage for example the effect of the reverse efflux on the temperature of adjacent aircraft parts, particularly the tyres, in order to settle the positions of the reverser and its outlets in the nacelle. A typical result (scaled to full-size temperatures and dimensions) is shown on Fig. 16. Confidence in the validity of these tests was given by the good correlation with the full-sized tests of the Derwent engine in a Meteor aircraft, referred to in Section 4.

Re-ingestion of exhaust gas into the engine, or into an adjacent engine, caused some concern, and model tests helped to develop outlet directions and vane arrangements to minimise this effect. Steam and hot air were discharged respectively from the outlet of a pair of engines (so that the efflux of one engine at a time could be distinguished visually, at conditions with both working), the engine intakes were coupled to a suction pump, and wind tunnel air was flowed over the model to represent all phases of the landing run from touchdown to standstill. Thermocouples at various points in the intakes indicated the amount and pattern of hot gas ingestion.

6.3. BENCH TESTING

In addition to the routine testing of the reversers to establish ahead and reverse performance, and mechanical integrity, various special tests were made at various times.

For example, in conjunction with the model tests on re-ingestion of exhaust gas, it was necessary to determine the effect of this on engines, and open-air runs were made with various temperature gradients imposed on the intake by setting up a Derwent engine to discharge its exhaust at a slant towards the test engine.

It has been found generally that the choice of outlet direction is usually critical; after avoiding those regions where the gas could be re-ingested, and those regions where the aircraft might be damaged by temperature and other effects, it is fortunate if a pair of gaps roughly on opposite sides of the nacelle can be found. Any design of reverser or outlet vane configuration which causes the efflux to fan out can hardly ever be successful.

The design with roughly square outlets, and with the gas controlled by closely spaced vanes, enables a narrow jet to be achieved. A side view of this (the jet being made visible by injecting oil into the jet pipe), shown on Fig. 17, illustrates this. The jet as viewed from the rear has a similar appearance.

Avon RA. 29 reverse thrust performance is shown on Fig. 18; the static curve is taken from test-bed measurements from which the 100 knots curve was calculated.

In forward thrust the loss is of the order of one half to three quarter per cent, due, in roughly equal parts, to losses due to turbulence where the gas passes pockets at the rear of the doors, and to losses due to seal leakage.

Up to the 22nd April 1959, the total engine running of the Avon reverser was 3,159 hours, including 6,032 cycles into reverse thrust, totalling 166 hours of reverse thrust running, and 462 hours (580 reversals) in aircraft.

Equivalent figures for the Conway unit were 1,038 hours total, including 2,586 reversals totalling 47 hours.

FIGURE 17. Smoke test on Avon slave reverser.

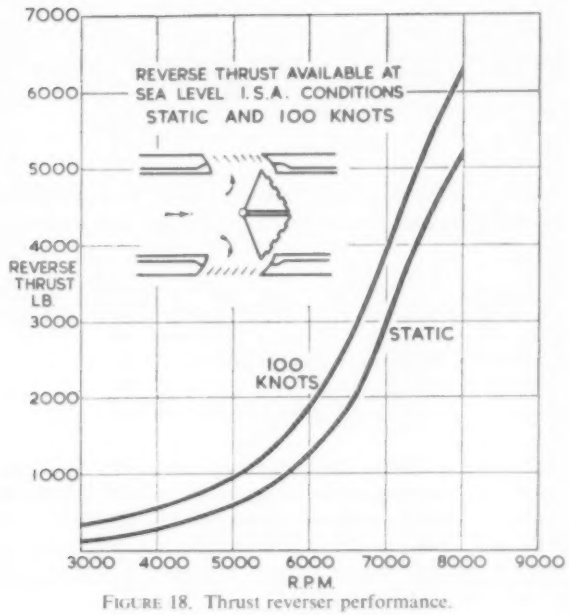

FIGURE 18. Thrust reverser performance.

6.4. FLIGHT TESTING

The bulk of the early flight testing was done on a Hawker Hunter with an RA. 28 engine. The unit was mounted aft of the rearmost main frame under the tailplane, with discharge ports on each side.

Initial flight tests in the Comet were made with a slave unit (giving reverse thrust only) mounted in one outer nacelle of a Comet 2. The aircraft was taxied, and also flown, on the remaining three engines with the reverse engine idling; this engine was then accelerated when reverse thrust was required.

An attempt to use reverse thrust in flight resulted in longitudinal instability of the aircraft due to disturbance of the air flowing over the tailplane.

7. Future Possibilities

After the reversers have been developed to a satisfactory standard of reliability, overhaul life and total life of main components, the next step will be to examine ways of reducing weight and cost.

Already—partly due to the mounting position on the engine—a start has been made in that the Conway unit is relatively lighter than the Avon one.

A logical development is to use reverse thrust in flight and thereby save the weight and cost of dive brakes. The main difficulty here is to ensure that the efflux does not affect control or stability of the aircraft.

Since at flight speeds the exhaust gas stream is bent backwards quite sharply with a lateral penetration of a few feet only, it seems that there is no fundamental obstacle involved.

In cases where precise and rapid changes of thrust are required in manoeuvring the aircraft, for instance in approaching the flight deck of an aircraft carrier, there are obvious possibilities in a fully variable reverser wherein without change of engine speed the pilot can vary the thrust through the full range from 100 per cent forward to 50 per cent reverse just as quickly as the reverser will operate. With present ones this is about half-a-second for full travel. There is no reason why the ability of a reverser to regain full thrust from some other position should not exceed in reliability that of an engine to accelerate.

There is no reason why reversers should not be used in a reheat installation—several projects have been prepared. It is necessary of course to install the reverser upstream of the burner and the layout of the Rolls-Royce unit is obviously suited to this arrangement.

For ducted fan engines, the only variety so far investigated is that using an aft fan driven by a free turbine. Two solutions have been proposed according to installational requirements—firstly to mount the reverser upstream of the free turbine so that when it is operated the turbine power is lost and the fan ceases to give forward thrust, or secondly, if the reverser has to be downstream then its effective outlet area in reverse should be similar to that of the free turbine nozzles so that there will be no pressure drop across them and, again, the power supply to the fan will automatically cease on application of reverse thrust.

8. Acknowledgments

The author thanks Rolls-Royce Ltd. for permission to publish this paper, and the Aviation Division, Dunlop Rubber Company, the de Havilland Aircraft Company Ltd. and the Boeing Aircraft Corporation for their approval of certain passages.

The views expressed—particularly those in Section 7—are those of the author and do not necessarily represent the official policy of the Company.

Definitions and Terms Relating to Aircraft Control Systems and Components

by

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1. Introduction

Recent developments in the control systems of aeroplanes have been such as to underline the need for new terms, and the need to remove any ambiguity relating to terms already in existence. The question has also been raised by the British Standards Institute in relation to the revision of the Glossary of Aeronautical Terms. The present paper examines the problem in the light of possible future developments, lists proposed terms with their definitions, and gives an outline of the underlying arguments. It is written in the spirit that in the field of systems of units, notation, and nomenclature "survival of the fittest" will always apply. The details of the nomenclature are not considered all-important, but we have tried to select the right concepts, to classify sensibly, and to produce accurate and general definitions. We expect many useful and amusing comments on nomenclature, but the other aspects are the fundamental ones, and we hope there will be some constructive criticism.

2. Proposed Terms and Definitions

Control (*Verb*). To deliberately exercise an influence on the dynamic state of a system.

(*Abstract noun*). The art or act of deliberately exercising an influence on the dynamic state of a system.

(*Concrete noun*). That part of a control system which is physically operated in order to adjust the degree or type of control.

The use of the word "control" as a concrete noun is deprecated; strongly with regard to an output element, but mildly with regard to an input element.

Motivator A device which produces changes in the forces and/or moments acting on an aircraft in order to control it. (An output element of a flight control system.)

Force Motivator A motivator intended to produce mainly force, and which can be further classified in terms of standard aircraft axes as follows:—

Fore-and-aft motivator (*X*-force)
Transverse motivator (*Y*-force)
Heave motivator (*Z*-force)*

Torque Motivator A motivator intended to produce mainly moment, and which can be further classified as:—

Roll motivator
Pitch motivator
Yaw motivator*

A force or torque motivator which produces an effect with respect to an axis materially different from a standard aircraft axis might be called a *mixed motivator*. For example, elevons produce a mixture of rolling and pitching moments.

A motivator which produces simultaneously a force and torque of comparable importance might be called a *compound motivator*. For example, a helicopter cyclic pitch device is a compound motivator which can produce both a fore-and-aft force plus pitching moment or transverse force plus rolling moment.

Actuator† A motor which drives any controlled member such as a motivator, and tends to produce linear or rotary motion of the member.

Series Actuators Independent actuators whose outputs are connected into the control system so as to make the resultant effect the sum of the individual contributions.

Parallel Actuators Independent actuators whose outputs are connected into the control system as alternatives, the unwanted connection at any time being normally broken.

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*It will be necessary to bring into use a single word for each type of motivator. *Roller, pitcher, yawer* may well find general acceptance, but names for the force motivators present more difficulty. Words compounded from Greek or Latin equivalents of fore/aft, up/down, and left/right may be worth considering. This leads to such words as:—

proaptor from Greek προ/απο (fore/aft),
catanator from Greek ανα/κατα (up/down),
aridextor from Greek αριστερος/δεξιος (left/right), or, in place of the last,
dexilator from Latin laevus/dexter (left/right).

†This is defined in B.S. 1523, Section 5, as "a servomotor producing a limited output motion". We think this to be too restrictive, and it inhibits the use of the perfectly good word "actuator" in a general way as we suggest here.

Since the human pilot can be regarded partly as an actuator, a single auto-stabiliser or auto-pilot actuator can be described as being in series or in parallel with the pilot or (loosely) with the control stick or other inceptor.

Inceptor An input element directly operated by the human pilot* in order to effect progressive control.

Selector An input element for selecting the type and/or magnitude of the control desired, *e.g.* height-control selector, and which remains in the chosen position in the absence of further human action or designed stimulus.

Transducer A device used for converting a signal or physical quantity of one kind into a corresponding physical quantity of another kind.

Sensor A transducer whose input variable is the original physical quantity to be measured.

Pick-off† A transducer whose input variable is a relative movement of two components, and whose output variable is usually electrical.

Pilot Control The state in being when inceptors are operated by a human pilot.

Automatic Control The state in being when the motivators are automatically operated in accordance with signals detected by instruments and with no pilot control through inceptors.

Flight Control System‡ The arrangement of all control elements such as inceptors, sensors, actuators, motivators, etc., which enable control forces and torques to be brought into play by the human pilot or otherwise.

Flight Instrument System An arrangement of elements such as sensors, amplifiers, servo-systems, together with means for display to the pilot of information on the orientation and flight path of an aircraft relative to a known datum.

Flight Reference Display A flight instrument system display of basic information such as air speed, bank angle, heading.

A reference display is likely to consist of several groups, for example, aerodynamic reference, dynamic reference, and situation display.

Flight Director Display A flight instrument system display of processed information, derived from basic information of the reference display type, and designed to simplify the pilot's task.

This display is intended to give a positive indication of good pilot control action rather than merely present information on the state of the aircraft.

Pilot Control System A control system used by the human pilot to manoeuvre the aircraft into, but not necessarily stabilise it with respect to, a desired flight condition.

Direct Control System A pilot control system in which the inceptor signal is directly transmitted to the motivator.

The transmission line may include a powered control unit, and also some non-mechanical (*e.g.* electrical) sections.

Powered Control System A pilot control system in which a power amplifier is placed between the inceptor and the motivator.

Manoeuvre Demand Control System A pilot control system in which the motivator deflections are automatically monitored in accordance with the motion of the aircraft in such a way that a unique pre-determined manoeuvre follows a simple input by the pilot.

Auto-Pilot Control System A control system which will automatically manoeuvre the aircraft into, and stabilise it with respect to, a demanded flight condition determined by a computer (human or otherwise) inside or outside the aircraft.

Unified (integrated) Control System† A system in which economy of engineering design has been effected by associating some of the functions of several systems previously separate.

Auto-Stabiliser An automatic device which improves the natural stability of an aircraft by operating motivators independently or as part of a pilot control system in such a way that the human pilot retains continuous control through his normal inceptors.

*The human pilot may in the case of a radio-controlled aircraft be outside the aircraft.

†This definition differs slightly from that given in B.S. 1523, Section 5.

‡*Flight* or *flying control system* should not be used to describe systems dealing with air traffic. These would be better termed *air traffic control systems.*

†It is later questioned whether this term, which has different implications at different times, really calls for definition.

An auto-stabiliser may be considered as part of an auto-pilot control system if and when it operates during automatically controlled flight.

Channel That section of a control system which determines the application of a particular motivator, *e.g.* elevator channel.

Multiple Channel A channel containing multiple components connected together in such a way that alternative channel sections exist for producing motivator application.

A large variety of forms for multiple channels is feasible, and two examples are given below where the alternative sections are themselves complete single channels but the methods of providing the alternatives are fundamentally different.

Multiplicated Channel A multiple channel consisting of one "normal" working channel together with one or more nominally identical stand-by channels.

Polygadic Channel A multiple channel consisting of two or more nominally identical component channels (sub-channels) all of which are normally working together.

Artificial Feel System A device which alters the sensations experienced by the pilot through those limbs that are in contact with the inceptors. Its purpose is to provide additional information regarding the state of control in order to simplify the pilot's task.

3. Discussion

In this section we shall consider the arguments leading up to the foregoing proposals. There is unfortunately a well-established practice of using the word control as a concrete noun, *e.g.* volume control, turn control, aircraft controls, but with the increasing complexity of aircraft control systems much confusion and ambiguity can arise. This practice has, therefore, been strictly avoided in this paper, and one consequence is a quest for a word to describe the force and/or moment producers. Motivator or effector has been proposed, but activator is a possible alternative. The latter is rejected on the grounds that it is too general a term, and is suggestive of chemical action. Effector is also general, but seems reasonably attractive, although it is in fact used by physiologists in relation to muscles (so is elevator!). Motivator has the advantage of implying the producing of motion or a tendency to produce motion, in the same way as the words motive and motivation.

The classification of the motivators according to whether they produce force or moment, and further according to the type of force or moment, presents a difficult problem in the choice of apt terms. It will be noted that we have not attempted to extend the meaning of the time-honoured terms aileron, elevator, and rudder. These terms have become associated with particular forms of motivators and so lack the necessary degree of generality.

The use of *series* and *parallel* to designate the type of actuator action is widespread. It is unfortunate that there is ambiguity in an analogy with electrical circuits, and present usage in the aircraft control field is correct for the analogy with series and parallel voltage generators.

At the other end of the control system we have input elements with the proposed names inceptors and selectors. In the past there has not been a distinction between the various types of "pilot's controls" but we suggest that there is a useful distinction to be made.

The definition proposed for selector is deliberately restrictive since a selector which determines magnitude of control may function as an inceptor when moved continually by the human operator. The need for some such restriction is perhaps best brought out by examples. Consider two familiar control devices of the conventional aeroplane:

(*a*) Flap selector lever.
(*b*) Trim tab wheel.

Each of these is a selector which determines magnitude of control as well as type. The pilot is unlikely to try to fly the aeroplane by continual adjustment of the flap lever, but it is well known that pilots have sometimes preferred to establish control through the trim tab rather than the elevator. When this occurs the trim wheel is being used as an inceptor.

Now consider two examples from the automatic control field:

(*i*) A spring-centred switch, which can operate only when a hand maintains sufficient force, and which causes the auto-pilot attitude datum to change at a constant rate.
(*ii*) A potentiometer with a centre detent, which can be moved only by hand but which, without any hand pressure, will stay wherever put, and which causes the auto-pilot to produce turning flight at a bank angle proportional to the potentiometer signal.

With (*i*) the human pilot can manoeuvre the aeroplane in pitch, and to do so must keep his hand on the attitude adjuster. In this respect the adjuster is an inceptor and when in use pilot control is implied according to our definitions. However, we may regard such a device as a selector since its central position corresponds to zero rate of pitch, and its displaced position to a constant rate of pitch: this outlook implies automatic control.

With (*ii*) we can have a similar duality of outlook but with the important difference that here the pilot need not keep his hand on the adjuster while the aeroplane is turning, and this presents a stronger argument for regarding this device as a selector.

As we have defined it above, the term pilot control includes the case of a human pilot moving inceptors on the ground, or in another aeroplane. Thus a "pilotless" aircraft may be either under pilot or automatic control.

A flight control system may operate in several different modes, various elements being in or out of action according to the particular mode selected at any time. It may be impossible to pin-point certain groups of elements and say that they comprise the auto-pilot, etc., since many elements will function in more than one mode. It is always possible, however, to say that the control system is operating in an auto-pilot *mode* when it is carrying out the functions of an auto-pilot.

Various auto-pilot modes are obtainable, but the system may be designed not to operate in the selected mode until another switch is engaged. Some modes may be complementary, *e.g.* speed and heading control: others mutually exclusive, *e.g.* attitude and height control. Current British practice is to refer to *attitude lock*, *speed lock*, etc. when the auto-pilot is selected to maintain constant attitude, or speed etc. and the selector is so marked. These terms are not very fortunate, being inconsistent in that when a selector is in, say, the *height lock* position, the human pilot can still alter the height datum through an inceptor. Current American usage is *attitude hold*, *speed hold*, etc.

Pilot mode is a suitable term for describing the state where the human pilot is taking control action based only on information obtained directly (*e.g.* natural horizon, acceleration effects) or from a flight instrument reference display. When, however, the pilot is basing his action on a flight director display, then we may refer to a *flight director mode*.

A particular stage of an aircraft flight is similarly described as a *phase*, for example the climb phase or approach phase, and special care is sometimes required to distinguish properly between a flight phase and a control mode.

Present development of automatic control equipment lays great emphasis on reliability coupled with safe change-over to an alternative control system in the event of dangerous malfunctioning. Multiple channels of various types are being considered, and definitions have been given in this paper of two basic forms only. It should be mentioned that S. Smith and Sons Ltd. have been using the words *multiplex*, *duplex*, *triplex*, etc. instead of *polygadic*, *dugadic*, *trigadic*, etc. When a distinction is drawn between two forms of multiple channels, it is desirable to use words that are semantically correct and not too similar. *Multiplex*, etc. can be and have been criticised on both scores, and F. J. Twiney suggested *polygadic*, etc. on the basis of the Greek-Latin jung-stem implying "yoked together".

We have not included in our list of definitions the term *manual control*. There are two widely accepted uses of this term. In the servo-mechanism field it is considered to be the opposite of automatic control; for this we have used the term *pilot control*. In the aeroplane field *manual control* has been used to mean the opposite of powered control. Since generally the term manual is used to imply that a human source of power is involved, rather than a human brain, there are good grounds for arguing against the servo-mechanism usage. On the other hand the term is by now well-established in the servo-mechanism sense, and we would have preferred to suggest an alternative term altogether. *Direct mechanical control system* is a qualified form of one of our terms which might be acceptable, although it is clearly open to criticism.

So-called integrated control systems are more correctly described as unified systems. The word "integration" has been used to describe the natural evolution of more economical engineering designs as a result of associating some of the functions of several systems which were previously separate, for instance, avoiding the use of separate servos for auto-pilot, auto-stabiliser and the manual control system. The phrase "integrated system" has therefore little meaning except to those people who are so familiar with the state of the art that at any particular time they know which systems (previously separate) can in a reasonable time be designed as a unified system with consequent saving of equipment and, perhaps, an improved performance.

4. Conclusions

The number of new terms introduced here, together with the difficulties experienced in deciding that the right concepts had been selected and suitably classified, underline that a review of the kind attempted here is now required.

One lesson to be learnt is that when terms are first sought for new developments these should be such as to embrace the most general concepts underlying these developments. A related difficulty, which can only become more emphasised with time, is that in a complex control systems it is difficult to classify in a unique manner the elements of which it is composed.

(Correspondence on these definitions and terms is invited.—Ed.)

Damage to Axial Compressors*

by

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Introduction

A centrifugal compressor rotor is quite robust, but the blading of an axial compressor looks horrifyingly fragile and very susceptible to damage by objects sucked into the engine. The introduction of axial compressor engines into airline service brings this again to the attention of designers and service engineers. The object of this paper is to outline the problem, and to describe one experimental approach to assessing the relative merits of different blade materials from the damage point of view.

Types of Damage

Practically all damage is sustained while running up, taking-off, or landing. How frequently it may be expected to occur, in its different ways, will therefore depend greatly on the conditions of service. Most experience so far obtained is on military aircraft; it has led to a better understanding of the nature of the trouble to be expected, but not the probable frequency of damage incidents.

Quite a small object can wreck an engine. Fig. 1 shows a typical compressor failure due to foreign body damage; it emphasises that once one or two blades have broken they start a cumulative failure of the remaining blades, finally destroying every aluminium alloy blade and mangling every steel blade. No compressor in any material can survive the fracture of a complete front stage blade, though pieces of blade tip have come off unnoticed. To start a failure it is only necessary for either a hard foreign body or a piece of blade to become trapped between stationary and moving blade rows.

Birds caused 10 per cent of the incidents in military service, of which 15 per cent were engine failures, and the remainder did not stop the engine. Sometimes the damage was only noticed on inspection. Large birds cause failures either by bending the inlet guide vanes into the rotor blades (Figs. 2 and 3), or by becoming lodged against the inlet guide vanes, causing a severe wake. The wake then excites a fatigue failure in a rotor blade. Ice caused only 0·4 per cent of the incidents, and not a single failure. Fig. 4 shows typical ice or hail damage. Civil aircraft would be expected to encounter more ice than military aircraft.

The remaining incidents were caused either by stones picked up off the airfield or by metallic objects left in the intake, or drawn into it after being detached from the aircraft. Only 2 per cent of these incidents caused failure, and in half the incidents the object drawn in was never identified. Figs. 5, 6 and 7 are examples of this damage. The leading and trailing edges of the blades are dented and chipped. Most minor damage is found near the blade tips, as the compressor rotation tends to throw the objects outwards. Many of these incidents should never have occurred at all; they were due to maintenance fitters leaving tools or rivets near the intake by mistake.

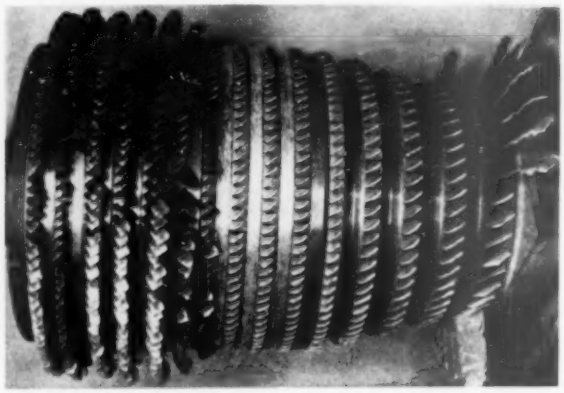


FIGURE 1. Typical compressor failure caused by a foreign body.

Intake Guards and Inlet Guide Vanes

It has sometimes been proposed that grids should be provided to protect engines at take-off. The method, which cannot be discussed in this short paper, is not often used; an effective guard throttles the engine badly, is very heavy, and not least is liable to lose its own component parts into the intake.

The inlet guide vanes might also be considered to be a form of intake guard. Improvements in compressor design could enable inlet guide vanes to be dispensed with in a two-spool engine, to improve the performance. An important question then arises as to whether this will make the compressor more fragile. Objects drawn in will strike the rotor blades much faster, so hard objects will damage them more. On the other hand, it can be argued that birds might well be cut up much more readily, instead of bending the inlet guide vanes into the rotor blades. There has been no case in which inlet guide vanes have saved an engine by holding an object lodged against them; as already mentioned it has led to a wake failure instead of a mechanical one.

*Read before the Derby Branch in February 1958 and awarded the 1959 N. E. Rowe Medal for the 21-26 years of age group.

FIGURE 2. Inlet guide vanes damaged by a bird. View from front.

FIGURE 3. Inlet guide vanes damaged by a bird. View from rear.

FIGURE 4. Compressor rotor blades damaged by ice.

FIGURE 5. Inlet guide vanes damaged by a small object.

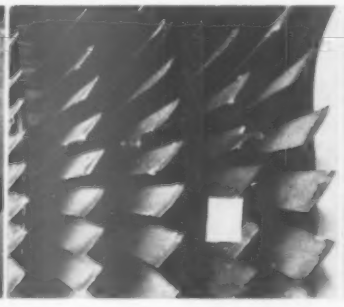


FIGURE 6. Rotor blades damaged by a small object.

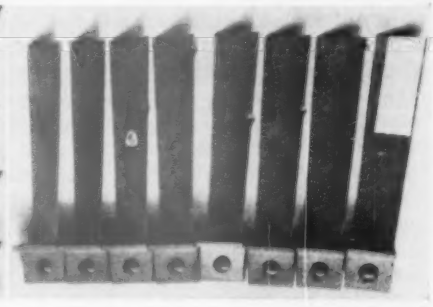


FIGURE 7. Rotor blades damaged by a small object.

The principal danger is, as usual, that one blade row would be bent into the next.

The Problem of Two Engines in a Pod

In some aircraft, engines are mounted in pairs in the same pod, or sharing the same intake. Experience has shown that when a compressor fails, from any cause, the engine "coughs" blades out of the front of the compressor as well as the back, because a violent compressor surge takes place. These blades are liable to enter the second engine and wreck it; cases of double failure of this kind have occurred. The sudden loss of both engines at one side means disaster to the aircraft. It can only be avoided by suitable intake design. In the past, some aircraft have been lucky; the engine "cough" snapped the variable inlet guide vanes to the closed position, reducing the available air space for the ejection of debris. This could not occur with fixed inlet guide vanes, or no guide vanes at all.

Blade Materials

Aluminium alloy and steel are the two popular blade materials for the early stages of a compressor, and titanium is a new possibility. A heavy blade needs a heavy disc, and steel is twice as heavy as titanium, and three times as heavy as aluminium. Is there any reason for believing that the weight penalty incurred by using the obviously stronger steel or titanium blades would save some compressor failures?

Clearly there are some foreign bodies which will smash any compressor, by becoming lodged between blades, if not directly; a spanner for example. It is much better to have aluminium alloy blades, in this case. Their kinetic energy is insufficient to burst them through the compressor casing. Steel blades, on the other hand, certainly have sufficient energy, and a very heavy steel casing may be necessary to contain broken blades.

At the other end of the scale, there is the much less dangerous object, like a small chip of gravel, which will fail neither steel nor aluminium blades, but leave them cut about. In between, there may be some objects which steel blades would withstand unbroken, but which aluminium blades would not. There is, however, no evidence of any such intermediate condition, and it is hard to imagine how it could arise, except perhaps in the case of a small bird. Any hard object, which is heavy enough to fracture or seriously to bend even an aluminium alloy blade, is certainly big enough to destroy any compressor, simply by becoming lodged between stationary and moving blades. Anything small enough to pass through is too light to do more than gash a blade. This has been demonstrated

both in service and in rig tests. Perhaps tests will be needed with model birds to establish the point for soft objects.

The relative merits of different materials can be resolved, by this argument, by deciding which reacts best when attacked by a shower of small stones or pieces of metal which do not break the blade directly, but reduce its fatigue strength by making a notch in it. Will the comparatively small chip taken out of a steel blade be as dangerous as the larger gash made in an aluminium alloy blade? This can be settled by laboratory tests, so that a background of factual information is available, against which the experience of airline operators can properly be interpreted.

Blade Damage Tests

A series of fatigue tests is therefore in progress on damaged compressor blades. In principle a large variety of damaged blades must be tested, in comparison with new blades. The standard fatigue test is used, in which at least six identical specimens are tested at a range of stress levels, to destruction or to ten million reversals. A curve of fatigue strength against number of reversals results. It is useless to test single blades, because the scatter in strength is so great. The tests described were carried out in the lowest natural frequency mode, familiarly known as "first flap," which is most vigorously excited in an engine. Damage near the root is clearly most important in this mode, and the possibility has been noted for future investigation that damage at certain critical points might induce failure in a more complex mode. The size of the blades used was determined by the wish to use existing identical blades in the different materials.

A few sets of blades damaged in service were tested first, but it was difficult to find six blades with similar damage. Blades had therefore to be damaged deliberately under controlled conditions. The second set of tests was a simple notch sensitivity check. Blades of identical design, but in aluminium alloy, steel and titanium alloy, had notches of equal size impressed in their leading edges near the root. Figs. 8, 9 and 10

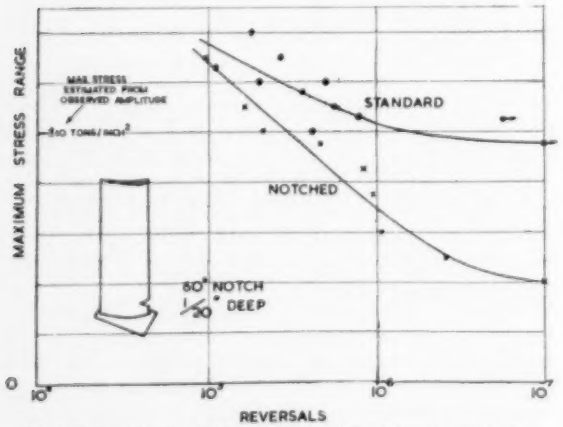


FIGURE 8. Notch fatigue tests on aluminium alloy blades.

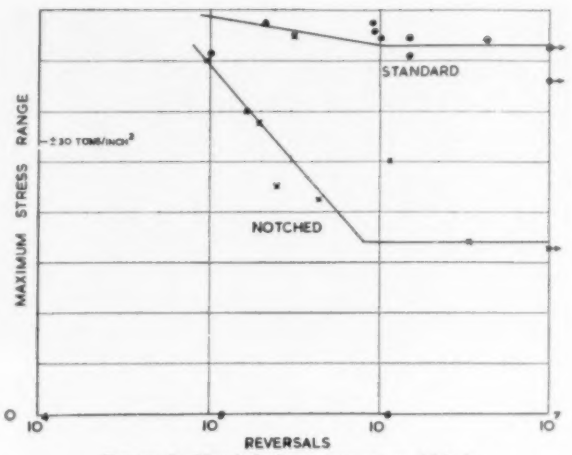


FIGURE 9. Notch fatigue tests on steel blades.

show the results of these tests. Aluminium alloy and steel blades showed equal reductions in strength of 45 per cent, but the titanium alloy was found to be twice as notch sensitive.

These results are not directly applicable to engine conditions, as the same object will obviously cause notches of varying size and sharpness in different materials. So for the third set of tests, small nuts and washers were fired at steel and aluminium alloy blades in a rig compressor. (Only this single row of blades was in the compressor.) This successfully reproduced typical engine damage, but in a larger quantity. Sets of blades with heavy damage, and with slight damage, near the root, were fatigue tested (Fig. 11). Figs. 12 and 13 show the results. The slight damage marks had no effect, and did not originate the failures. The severe damage reduced the strength of both steel and aluminium alloy blades by 20 per cent.

Small stones about ½ in. across (of average weight 1/10 oz.) were used to damage another set of steel and aluminium alloy blades (Fig. 14). In this case, the strength of the steel blades was reduced by 5 per cent and of the aluminium alloy blades by 15 per cent (Figs. 15 and 16). Other tests are planned, in which blades clamped in a vice will be damaged by firing metal pellets at them. This damage will be more easily

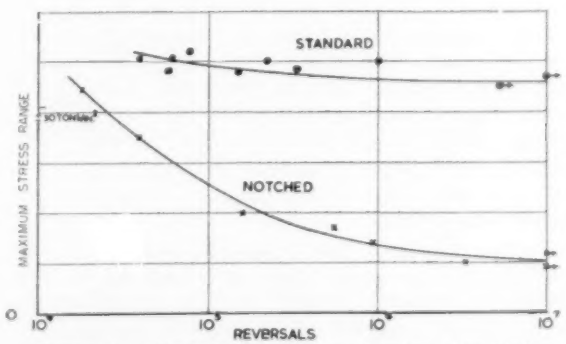
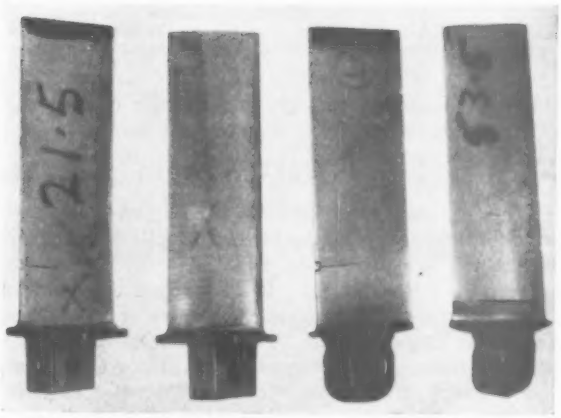


FIGURE 10. Notch fatigue tests on titanium alloy blades.



Aluminium Alloy Blades		*Steel Blades*	
large damage mark	small damage mark	large damage mark	small damage mark

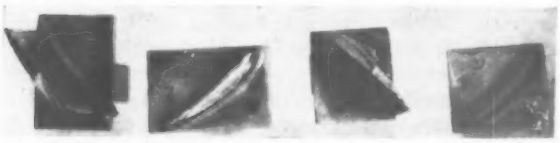


FIGURE 11. Blades damaged deliberately in a compressor rig and fatigue tested to failure.

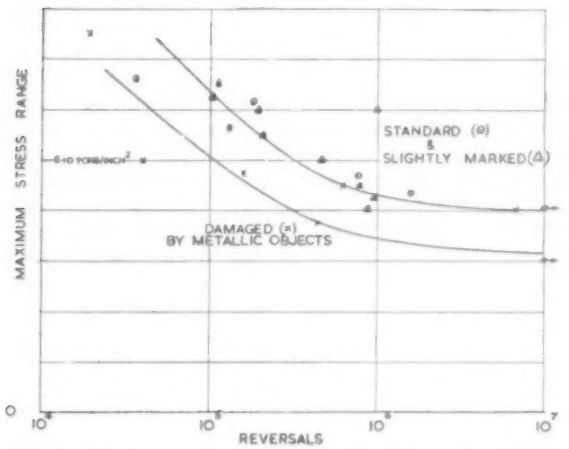


FIGURE 12. Damage fatigue tests on aluminium alloy blades.

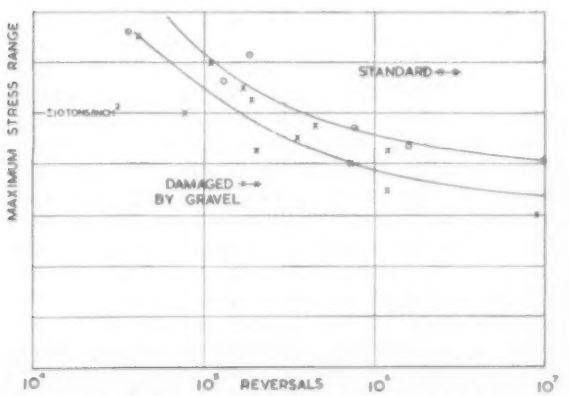
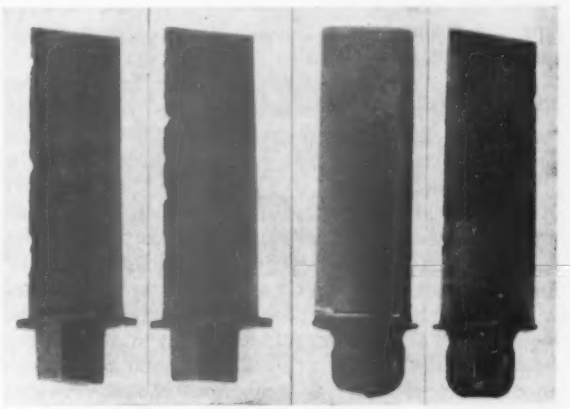


FIGURE 15. Gravel damage fatigue tests on aluminium alloy blades.



Alminium Alloy *Steel*

FIGURE 14. Blades damaged deliberately in a compressor rig by gravel and fatigue tested.

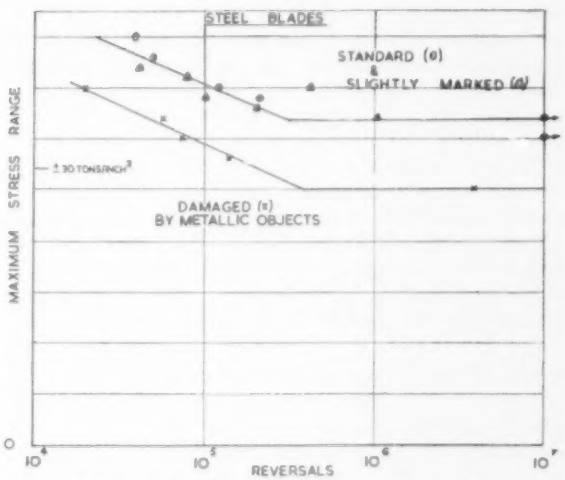


FIGURE 13. Damage fatigue tests on steel blades.

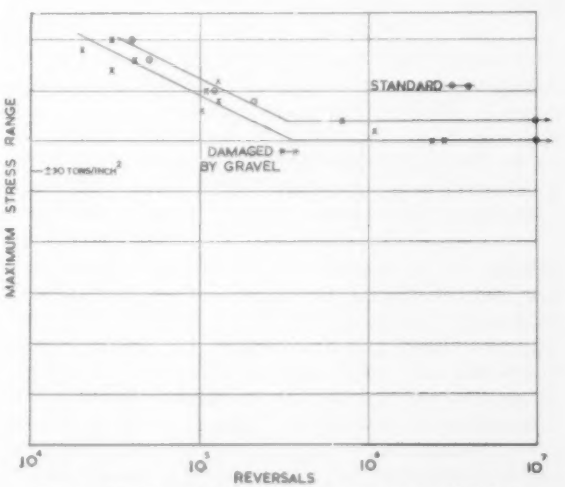


FIGURE 16. Gravel damage fatigue tests on steel blades.

reproduced than that inflicted in a compressor rig. Titanium blades will also be tested.

The interpretation of these results rests on the theory, confirmed approximately by experimental results, that the maximum stress induced in a particular design of a blade in a particular compressor stage is in general proportional to $\sqrt{(\text{Young's modulus} \times \text{density})}$ of the material. The stress in a steel blade is therefore three times the stress in an aluminium alloy blade doing the same duty. As the fatigue strength is about four times as great, steel is only slightly better. Titanium, on the other hand, will show a stress only 50 per cent higher than the aluminium alloy, but has a fatigue strength almost as high as steel. Titanium is therefore an excellent material for compressor blades, provided they remain undamaged. Turning now to the case of damaged blades, as the fatigue strength is only slightly reduced in aluminium alloy and steel, neither shows any important net advantage. The advantage of titanium over these other two materials is lost by the damage, however.

Further tests are essential to draw firm and satisfactory conclusions, and to enlarge upon the simplified account given. It is essentially a statistical problem; the more data is accumulated the better.

Conclusions

In some cases a foreign body entering an engine will wreck it, irrespective of the blade material. More often, blades will be chipped and dented, but the engine will survive the initial impact. It is therefore desirable to have blades designed to minimise the risk of subsequent short time fatigue failure. Tests on blades with representative damage have suggested that, taking account of the different stresses expected in different materials, aluminium, steel and probably titanium blades, when damaged, would all be working at about the same proportion of their fatigue strength. Aluminium alloy blades would therefore be just as safe as steel blades.

The validity of this approach depends essentially on the idea that the number of cases in which aluminium alloy blades would be broken immediately, but steel blades would survive, is negligible in comparison both with unavoidable failures and with the incidents in which minor damage occurs. The investigation is continuing.

Inflammability and Electrical Studies of Foams Which may Occur at Altitude by De-Aeration of Aviation Turbine Fuels

by

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Introduction

Air dissolves in aircraft fuels to an extent directly proportional to the ambient pressure, so that when fuel which has been stored at sea-level atmospheric pressure is taken up to a high altitude, there is a tendency for air to come out of solution. In certain circumstances, which are later described in detail, air bubbles can be liberated very violently from fuels in aircraft tanks at high altitude and a thick foam can form on the surface for a short time.

The production of fuel foams by degassing has posed a certain problem; foams, being intimate mixtures of air and fuel, may well be inflammable; furthermore, the rising of air bubbles through fuel can result in the accumulation of electrical charge in the foam giving rise to the possibility of a source of ignition. An inflammable medium and a source of ignition, the two essential ingredients for an explosion, might thus be produced simultaneously in a fuel tank.

This problem has been studied in two parts. Firstly, the ability of such foams to support flames has been determined; and secondly, the magnitude of electrical charges produced during the foaming process has been established.

The Release of Dissolved Air from the Fuel

THE PROCESS OF AIR RELEASE

The tendency of air to emerge from fuel at reduced pressure is suppressed by the surface tension of the fuel. The pressure inside submerged bubbles of gas needed to oppose the surface tension of a liquid is extremely high when the bubbles are very small, being inversely proportional to the radius of curvature of the bubbles. Since all bubbles produced during degassing must start growing from a radius of zero, no bubbles will form at all unless some cavities of a minimum size, depending on the degree of super-saturation, are produced in the fuel by mechanical means.

The altitude at which dissolved gas is liberated from the fuel in this way depends on the degree of mechanical agitation of the liquid. Switching on a booster pump at high altitude can result in immediate and very rapid gas evolution, giving rise to a layer of foam some inches thick, if, before the starting of the pump, the mechanical agitation of the fuel was insufficient for bubble formation.

The behaviour of fuel in a tank containing a booster pump was observed visually under conditions equivalent to high altitudes, by placing the tank inside an altitude chamber containing suitable observation ports. With the fuel quiescent the air pressure above the fuel was reduced until the required altitude was reached. At this point the booster pump was switched on. This procedure simulated flight plans in common use, in which booster pumps are switched off after take-off in all fuel tanks except those used during climb—usually the fuselage tanks. Often, cruising altitude is reached before these tanks are completely emptied, and other tanks are brought into use at altitude by switching on their booster pumps.

In the experiments described, immediately the pump was switched on, extensive evolution of air from the fuel began. The evolution was first observed in the vicinity of the pump, but rapidly spread throughout the whole volume of fuel in the tank. After reaching a maximum the rate of evolution died away to zero, the whole process occupying about 30 seconds. During evolution, a layer of fine foam occurred on the surface of the fuel to a depth of several inches.

In a special apparatus described later, in which de-aeration was initiated by means of a small impeller, the process was studied more fully, and Fig. 1 shows the typical appearance of a foam during three stages of its life. Clearly the rate of release of air will be an important variable in the subsequent phenomena, and it was shown that the rate of release is an exponential function of time.

As might be expected, the violence of the foaming increased with the altitude at which foaming was initiated. With the particular apparatus referred to the maximum rate of air release was found to be proportional to $(A - 18{,}000)$ when A was the altitude in feet at which de-aeration was initiated. Hence increases in altitude above 18,000 ft. had a much more than proportional effect on the violence of the foaming.

As already explained, the exact dependence of the rate of air release upon altitude can be expected to

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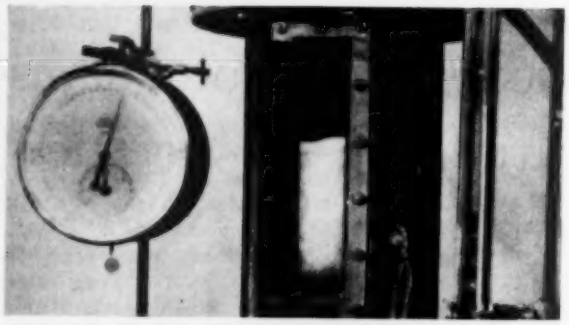
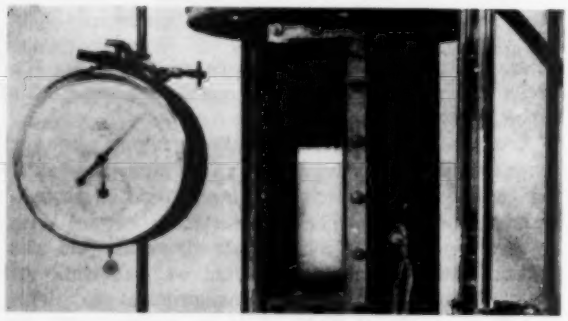
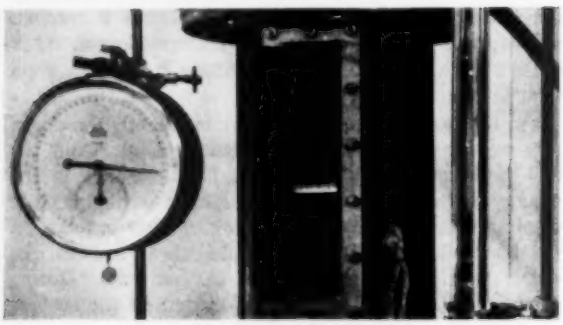


3 sec. after impeller switched on.



7·5 sec. after impeller switched on.



16·3 sec. after impeller switched on.

Fuel—SR 312 Fuel temp.—17°C Altitude—31,000 ft.

FIGURE 1. Progress of foam in altitude chamber.

vary according to the degree of mechanical agitation initiating the process.

COMPOSITION OF LIBERATED GAS

Oxygen has a higher solubility coefficient in fuels than has nitrogen, and the gas dissolved is thus richer in oxygen than is normal air. It would be expected from thermodynamic reasoning that during de-gassing the gas first evolved would be close in composition to air, but the oxygen concentration of the gas evolved would rise continuously as more gas was released. Since the ability of flame to propagate through a mixture normally depends markedly upon the oxygen concentration, it was important to establish the oxygen concentration likely to be present in a foam. The aim of the work was to define the extreme limits of any possible hazard, so that the figure needed for any given altitude was the *maximum* oxygen concentration that could be attained.

TABLE I

PROPERTIES OF FUELS

	Kerosine to D.Eng. R.D.2482 specification		*Gas oil*	
Specific gravity 60°/60°F	0·807		0·827	
Flash point °C	52		74	
Viscosity at 100°F cS	1·5		3·2	
Vapour pressure mm.Hg.	before expt.	after expt.	before expt.	after expt.
at 0°C	0·4	0·3	0·098	0·099
10°C	0·8	0·7	0·20	0·20
20°C	1·4	1·2	0·40	0·39
30°C	2·4	2·0	0·75	0·72

The pressure on thirty-five litres of fuel contained in a drum was reduced slowly by means of a Toepler pump of 200 ml. capacity, samples delivered by the pump being regularly analysed for oxygen in an Orsat apparatus. Static pressure was measured by a manometer and the gases were liberated smoothly by a screw paddle rotating in the liquid. Both kerosine to D.Eng. R.D.2482 specification and gas oil, which is an example of a fuel of very low volatility, were examined, the experiments on both being made in duplicate. (Fuel properties are given in Table I.)

The results are given in Fig. 2 where oxygen concentration in the evolved gas is plotted against the altitude corresponding to the pressure at which it was evolved. It may be seen that substantially the same results are given by both kerosine and gas oil. This is not surprising, since the nature of the curve is determined by the *ratio* of solubilities of oxygen and nitrogen in a given solvent, rather than by the individual level of each.

In an ideal solvent (in the thermodynamic sense) the ratio of the solubility of nitrogen to that of oxygen is 0·625 at 20°C, and little variation in this value with temperature should occur over the temperature range of interest in this particular problem. It is possible to calculate the composition of gas liberated from an ideal system using the above ratio of solubilities, and agreement with the experimental results for kerosine and gas oil is remarkably good. It appears reasonable therefore to assume that this relationship holds fairly well for most hydrocarbon fuels.

Since it can be shown theoretically that these curves represent the maximum concentration of oxygen that can be obtained from these fuels at a given altitude, we now have the information necessary for estimating the most hazardous composition that can be evolved.

Flame Propagation Through Foams

A technique analogous to that of measuring the limits of inflammability of gaseous mixtures was developed for assessing the explosive behaviour of foams. Foams were produced in a trough two feet six

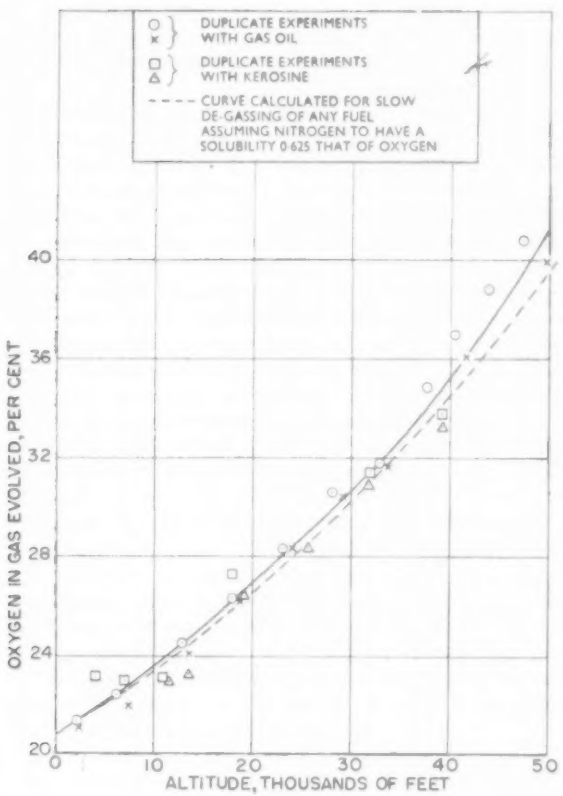


FIGURE 2. Variation of oxygen concentration in liberated gas with altitude.

inches long and six inches wide and were ignited at one end. A flame was adjudged to propagate only if it travelled to the other end of the trough. The bottom of the trough was covered with a plate perforated all over with holes 0·002 in. diameter spaced 0·02 in. apart. Underlying this plate was a compartment subdivided into twenty-eight sections, into each of which oxygen-nitrogen mixtures were fed at a controlled rate. In this manner foam was formed fairly evenly over all the surface. The whole trough was contained in an altitude chamber. The influence on flame propagation of (*a*) oxygen concentration in the gas bubbles, (*b*) ambient pressure, (*c*) fuel temperature and (*d*) rate of foaming were studied. Two fuels were again used: aviation kerosine of D.Eng.R.D.2482 type and a gas oil. This enabled the effect of fuel volatility to be assessed. (Wide range fuel of D.Eng.R.D.2486 (or JP.4) type was deliberately not studied because its vapour pressure is already sufficient to give explosive mixtures with air over a very wide range of operating conditions. Any contribution of foaming towards further widening the limits could not therefore extend any hazard greatly.)

The first point of significance which was established was that flame propagation was critically affected by the oxygen concentration in the bubbles. In fact the most convenient experimental procedure was to find the critical concentration of oxygen at which propagation would just take place, as various other factors were altered systematically.

It was frequently found that the critical oxygen concentration went through a minimum and then increased again as bubbling rates were increased. Since the work was related to the defining of a possible hazard, this minimum value was the quantity immediately required, and curves were not taken very far beyond the minimum point. Only where a minimum was not found were the bubbling rates increased to the maximum of which the apparatus was capable. The limit was then set at higher pressures by the maximum gas flow rates that could be conveniently obtained, and at lower pressures by the overflowing of foam from the trough.

One variable which was not investigated systematically was bubble size. Preliminary work indicated that the smaller the bubble size the more easily did flames propagate. Most of the work was carried out with the smallest bubble sizes that could be obtained with the equipment, *i.e.* with the smallest holes in the perforated plate, and these corresponded reasonably well with the bubble sizes of foams produced by de-gassing.

During the course of a number of experiments the fuel became weathered by the continual bubbling of gas through it. It was therefore changed frequently. The vapour pressures of typical discarded samples of fuels are given in Table I and are seen to be somewhat lower than those of the fresh fuels. The differences are not great however, and it appears that the weathered fuels were still fairly representative of the fresh ones.

A considerable amount of data was collected which may be qualitatively summarised as follows:

(*a*) as mentioned previously, an increase in oxygen concentration greatly promoted flame propagation;

(*b*) increase of fuel temperature greatly promoted flame propagation;

(*c*) decrease of ambient pressure had little effect on flame propagation at low fuel temperatures, but greatly promoted it at higher fuel temperatures;

(*d*) there was an optimum rate of foam formation at which flame propagated most easily;

(*e*) covering the trough with a lid greatly enhanced flame propagation.

A ciné film of a "flame" passing through a thin kerosine foam threw some light on the mode of propagation. Close examination of the ciné film run in slow motion shows that flame spreads across a thin foam essentially by the physical movement of burning droplets which are projected presumably by the bursting of bubbles. When a burning droplet alights on a new bubble it can give rise to a number of new burning droplets which carry on the process. The analogy that this mode of propagation bears to a chain reaction is striking, and it seems reasonable that the critical conditions for continued flame propagation are achieved when, on the average, one burning droplet produces one new burning droplet during its lifetime.

Thick foams present a somewhat different picture. Here the heat flow from the flame breaks down the foam just in front of it, so that a dense spray of drop-

lets is produced through which the flame propagates with a front which is better defined. It is not clear whether this propagation involves the successive ignition of droplets by already burning droplets, or whether the premixing of vaporised fuel with air in advance of the flame front contributes significantly to the process.

FLAME SPEEDS

Velocities of flame propagation were not measured but appeared to be considerably less than those of vapour-air mixtures. It was frequently observed that secondary explosions of much higher flame speed occurred in the burnt gases in the wake of the primary flame. These probably resulted from the mixing of fresh air, which was still bubbling through the fuel, with fuel which had been vaporised by the primary flame. Far greater pressures were generated by the secondary explosions than by the primary ones. The sequence of events giving rise to the highest explosion pressures is therefore: (1) breakdown of foam to form a spray, (2) slow primary flame propagation through this spray, and (3) fast secondary flame propagation through vapour-air mixtures in the wake of the primary flames.

FLIGHT CONDITIONS NECESSARY FOR PRODUCTION OF INFLAMMABLE FOAMS

It was established by these experiments that flames can propagate through foams of air in fuels below their flash points over a range of conditions. The conditions likely to be prevailing in aircraft fuel tanks during de-gassing of fuels can also be estimated from the results of the work on the composition of liberated gases. It now remains to set these conditions against one another in order to assess whether an inflammable mixture may be present during flight.

The results need to be expressed in a suitable manner in order to effect a quantitative comparison. Fig. 3 illustrates the manner in which this is done. The results are for gas oil. On this figure the curve sloping upwards to the right is that shown in Fig. 2, but to a different scale. It shows the percentage of oxygen that would be *available* in a foam as the altitude increases. On the same axes the results of the work on flame propagation are summarised in the form of curves showing for a given fuel temperature the relationship between altitude and the minimum concentration of oxygen *required* in a foam to support a flame. By comparing the minimum percentage of oxygen that is needed for flame propagation through a foam, with the maximum percentage of oxygen that can be present in the gas being liberated at that altitude, the possible existence or otherwise of an inflammable mixture can be established.

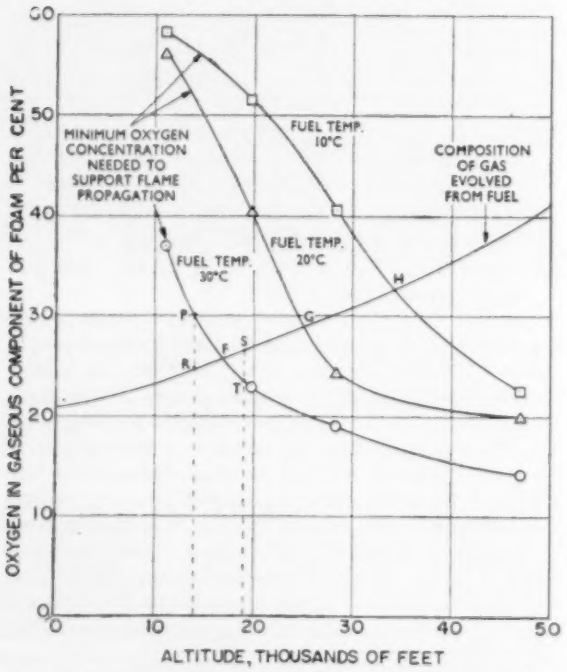


FIGURE 3. A comparison of oxygen concentration in evolved gases, with that required for flame propagation through foams of gas oil.

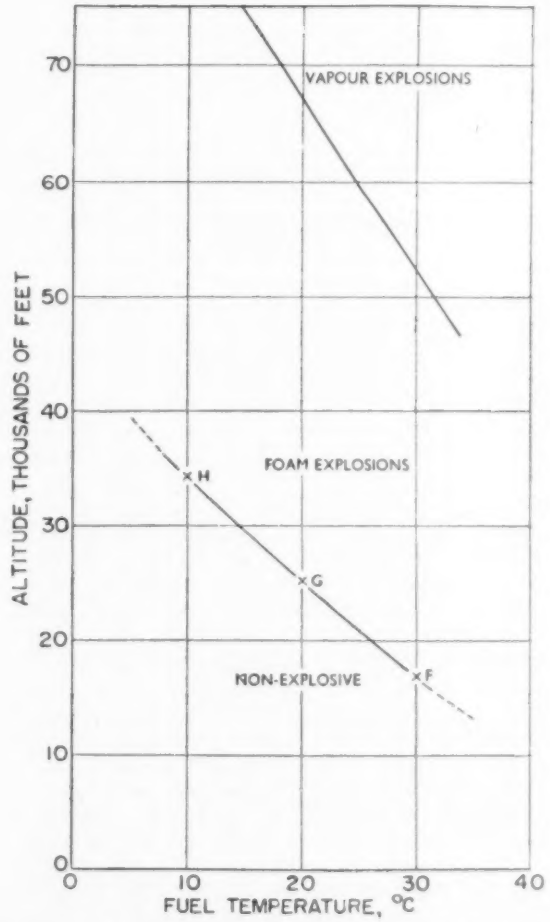


FIGURE 4. Boundary conditions for explosions in the free space above gas oil in fuel tanks.

Consider for example the fuel at 30°C. At an altitude of 14,000 feet 30 per cent of oxygen would be needed to sustain an explosive flame in the foam (point *P*). However, not more than 24·6 per cent of oxygen (point *R*) could be present in the gas evolved, and so flame would not propagate. At an altitude of 19,000 feet, however, only 23·5 per cent oxygen would be needed for propagation (point *T*), but 26·5 per cent might be available. An explosion could therefore take place. The point of intersection *F* represents the critical altitude above which explosion becomes possible. Similar reasoning applies to the points of intersection *G* and *H* and it now becomes possible to plot the critical altitude for flame propagation against fuel temperature. This is done in Fig. 4, while Fig. 5 shows a similar curve for kerosine. For comparison, the boundary conditions for vapour-air explosions as calculated from the flash points of the fuels and their vapour pressure-temperature relationships are also shown.

These figures demonstrate that the possibility of foam ignitions greatly extends the range of conditions in which inflammable media might exist. This range for kerosine embraces conditions which are certain to be encountered regularly by high altitude jet aeroplanes and frequently, by the lower-flying turbo-prop aircraft.

The parallel investigation into the production of electrostatic charge by the rise of air bubbles therefore now assumes very great importance.

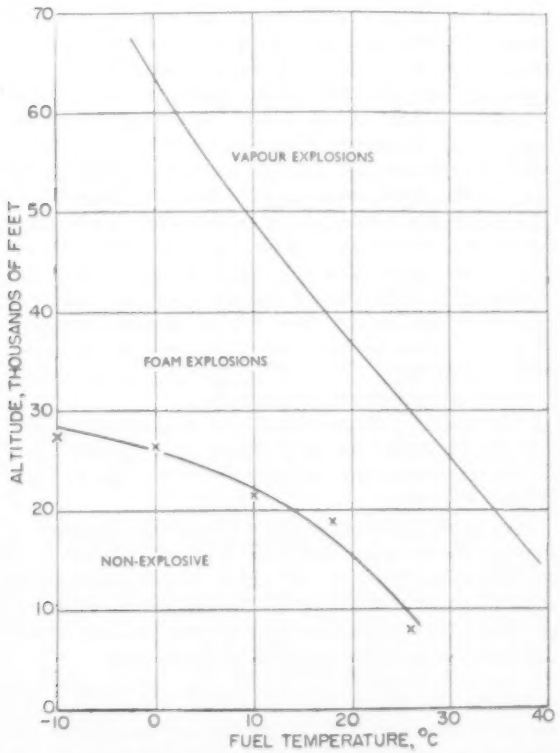


FIGURE 5. Boundary conditions for explosions in the free space above kerosine in fuel tanks.

The Electrostatic Charging of Foams

Distillate fuels normally consist of non-polar hydrocarbon compounds and thus have the properties of very good electrical insulators. However, minute quantities of certain organic or organo-metallic compounds may also be present which are capable of ionising slightly and thus of modifying the electrical behaviour of the fuel. Some of these materials may also become adsorbed on a fuel/air or fuel/solid interface.

When this is the case, a minute electric charge is associated closely with the interface. Normally, the compensating charge of opposite polarity can be considered as being distributed in the fuel behind the interface. If, now, there is relative movement between the interface and the body of fuel, these charges of opposite polarity become physically separated, mechanical work is done on them and thus a potential difference is set up.

Such a state of affairs exists when air bubbles rise through the fuel to its free surface.

As soon as a potential difference is set up, of course, the charges of opposite polarity tend to migrate towards each other. However, as already mentioned, fuel conductivity is normally very small, and such migration is therefore slow. The rate at which charges associated with air bubbles rise to the fuel surface can easily be high, and even though charges simultaneously leak away through the fuel, a concentration of charge can occur at the fuel surface.

To assess whether such behaviour constitutes a hazard, it must be determined whether the consequent electrical stresses in the air space above the fuel are sufficient to cause spark breakdown and also whether, if such a breakdown occurs, the energy in the resultant spark is sufficient to cause ignition of an inflammable fuel/air mixture.

The circumstances in which foaming might occur in an aircraft fuel tank were therefore studied. Two distinct cases arise: first, when a booster pump is running only partly submerged in a nearly empty tank; and second, when dissolved air comes violently out of solution at altitude in the manner already described.

A short experiment with a booster pump fitted in a deep open tray established that a thin layer of foam does indeed form around the pump as the level of fuel in the tank drops just below the upper limit of the pump intake screen. As the fuel level drops even farther, the foaming increases around the pump and spreads, again thinly, over most of the free surface of the fuel.

However, no electrical charge could be detected on such a foam.

Efforts were therefore concentrated on studying the electrical behaviour of the foam produced at altitude, and for this purpose a cylindrical pressure-tight tank was constructed carrying a transparent Perspex panel in one side. Fuel was placed in the tank and the air pressure above the fuel was reduced by means of a vacuum pump, a controlled air leak into the tank enabling the pressure to be maintained constant at any value corresponding to altitudes between sea level and

45,000 ft. An impeller was mounted at the bottom of the tank and, when the required pressure was reached, this impeller was switched on, thus initiating the violent de-aeration which resulted in a foam layer on the fuel surface.

The electrostatic charge was measured by supporting a flat disc of perforated metal on the surface of the foam. The disc was fixed at the lower end of a steel rod which passed through a large air-tight Perspex gland in the top cover of the test chamber. Outside the chamber the rod carried an insulated holder which enabled the disc to be raised and lowered by hand so that it remained in the foam surface throughout the evolution of air.

The charge generated in the foam was transferred to the disc by contact, and allowed to leak away to earth through a very high known resistance. The resulting current was measured by connecting a Lindemann electrometer across this known resistance, and readings were taken at intervals throughout the air evolution.

Before repeatable results could be obtained certain precautions were found to be necessary. The fuel had to be exposed to the air for some time before complete saturation with air could be relied upon, and then each sample could be used only once in the apparatus. A re-test of a used sample invariably gave about half the electrostatic charge of a fresh sample.

The reading of the electrometer showed a maximum very soon after initiation of the de-aeration, and then it gradually decreased as the foaming died out. Superimposed on this general trend were random minor deflections which created some difficulties in reading the instrument at small time intervals, but eventually a satisfactory technique was developed.

By this means the leakage current could be plotted against time for each test condition. Graphical integration of this type of plot gave immediately the total charge measured during air evolution and comparisons between different test conditions were made on the basis of this total charge.

In order to relate the experiments to the operation of an aircraft, the effects of altitude, fuel temperature (particularly in the presence of water) and nature of the fuel, with particular reference to the presence of trace ionisable components, were explored briefly. These trace substances may change both the magnitude of the charge separated and the electrical conductivity of the fuel.

The curve of Fig. 6 shows the relationship between total charge and altitude for aviation kerosine at one temperature. It is seen that the charge was practically zero below 20,000 ft. and this is in accordance with an observed absence of violent foaming below this altitude in this apparatus. The charge increased with the altitude at which the impeller (corresponding, say, to a booster pump in the aircraft) was first switched on. Again this is in accordance with the increased violence of foaming with increased altitude, as already described.

The effect of fuel temperature for aviation kerosine at one altitude was found to be, in general, small.

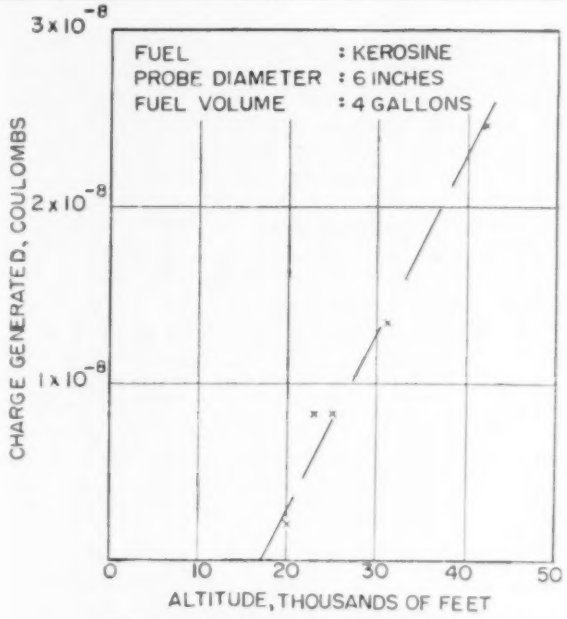


FIGURE 6. Variation of charge with altitude.

However, at first no precautions were taken to prevent the fuel drying as temperature was lowered, and somewhat erratic results were obtained at sub-zero temperatures. This behaviour was thought to be due to a third phase—water or ice—sometimes being present.

To check this theory, two samples were drawn from a drum which had been left for 24 hours in a humid atmosphere, and each was split into two. For the first sample, one sub-sample was cooled down in an open container, and the other was cooled down in a closed container with no ullage space. After cooling for five hours the fuel was transferred to the altitude chamber, without contact with the ambient atmosphere in the case of the latter sub-sample, and tests were made. The procedure resulted in the formation in the latter sub-sample of a haze of water precipitated from solution as the temperature fell. The same procedure was employed for the second sample with the difference that both sub-samples were left in the cold room for 65 hours. This resulted in the sub-sample in the closed container forming a haze of ice particles, while that in the open container was dry and clear.

The results of these comparative tests clearly showed that the presence of a third phase, as a haze of water or ice, increased the maximum possible charge by a factor of about two.

As explained above the electrostatic charging is thought to be associated with the presence of trace materials in the fuel. It seems possible that these could occur either naturally or by contamination of the fuel after manufacture, and so comparisons between different types of fuel are of little significance.

A more detailed study of the effects of trace materials was made by comparing the charges produced, under constant conditions, by samples of the same base kerosine to which had been added various materials in the concentration 0·005 per cent *w*.

Although most of the additives tested had little effect, two additives succeeded in altering the charging by one order of magnitude. This is an important result, since materials similar to these two have been proposed as corrosion inhibitors, added to the fuel to prevent severe corrosion of long pipelines.

The effect of concentration of one of the additives was studied and Fig. 7 shows that the maximum charging occurred with a concentration of 0·0018 per cent *w*. In this figure, the charge per unit volume of fuel is given. By comparison with the base fuel, fourteen times the charge was detected. When the effect of an ice haze is also considered, it might be expected that a further doubling of the charge developed would take place.

Some idea of the significance of these charges can be obtained as follows.

If the disc is allowed to remain insulated from earth, and it is assumed that the electrical behaviour of the system is not changed thereby, then the electrical energy is proportional to the square of the charge collected by the plate, and inversely proportional to the electrical capacity of the system (which was measured). The combined presence of the additive and the ice haze described above, might thus raise this energy by a factor of $(14 \times 2)^2$, *i.e.* nearly 1,000.

An experiment to investigate the combined effect confirmed this expectation. Charge corresponding nominally to an energy of $2{\cdot}8 \times 10^{-4}$ Joules was measured, as compared with charge corresponding nominally to 3×10^{-7} Joules for an untreated fuel.

This figure must now be compared with the figure 3×10^{-4} Joules quoted by Blanc, Guest, Von Elbe and Lewis[1] for the energy required to ignite the most favourable propane/air mixture at the appropriate pressure. Thus untreated fuel generated a charge energy at least 1,000 times below the possibly dangerous level in the particular apparatus being used.

In actual fact, when the disc is insulated from earth its voltage will increase, and charge will leak away at a significant rate through the foam, at the same time as fresh charge is being brought to the surface. Even less energy will then be available for discharge.

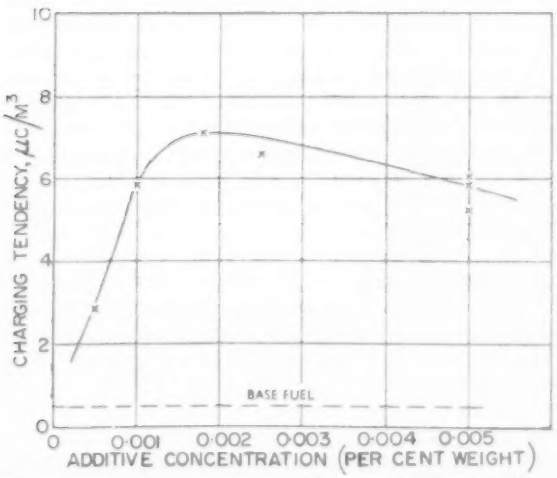


FIGURE 7. Variation of charge with concentration of additive showing the maximum charge measured compared with the charge from the base fuel.

The characteristic of the fuel which controls this leakage is the " relaxation time,"* which is given by:

$$\tau = \frac{\varepsilon \varepsilon_0}{\kappa} \text{ seconds.}$$

where ε = dielectric constant of the fuel.
ε_0 = absolute dielectric constant of vacuum, $8{\cdot}854 \times 10^{-12}$ ampere-seconds/volt-metres,
κ = conductivity of fuel in mho/m.

The samples of aviation kerosine used in the experiments had conductivities between $2{\cdot}5 \times 10^{-12}$ and 10×10^{-12} mho/m., and so had values of τ between about 7 and 2 seconds. Results showed that well within this time the peak of voltage, and hence the greatest likelihood of a spark, had occurred, the generation of charge being so rapid that only a small proportion would have been conducted away before the peak. At this point, however, only half the total charge had been generated so that only about one quarter of the energy estimated in the foregoing manner would have been available for the discharge. This would then have been, with untreated fuel in the test rig, some 4,000 times below the energy possibly required for ignition.

An Assessment of the Likelihood of Ignition

It has been shown that the foams formed during the degassing of kerosine are inflammable in certain circumstances. This conclusion must, however, be kept in perspective, since the condition lasts only for the duration of the degassing process (which may be, say, thirty seconds). In contrast, wide range fuel would render fuel tank atmospheres inflammable for longer times over a very wide range of operating conditions.

Even so the absence of hazard with kerosine in normal operating conditions must now depend upon the absence of a source of ignition in the fuel tank during the time the inflammable foam may be present.

It has been shown that in the experimental apparatus untreated fuels produced an electrostatic charge at least 4,000 times too small for ignition. Before accepting this figure, however, it is necessary to consider how far results obtained in the laboratory apparatus apply to the much larger fuel tanks employed in the aircraft.

It has been possible to treat the subject theoretically, and to examine individually the factors involved in scaling up. Adequate correlation with experimental results has been found enabling the maximum voltage reached to be expressed in the form:—

$$V_{max} \propto AQ\,f(\tau)$$

where A is dependent on the violence of foaming,
Q is the total charge released by the fuel in foaming,
and τ is the relaxation time previously described.

*See *Electrostatics in the Petroleum Industry* by A. Klinkenberg and J. L. van der Minne, Elsevier Publishing Co., 1958.

(This is analogous to an expression $E \propto i\tau$ developed* for the electrostatic charging of fuel in steady flow pipes. That $f(\tau)$ appears in place of τ is due to the transient nature of the foaming as opposed to the equilibrium conditions set up in flow through pipes.)

Assessments of the maximum voltage and charge energy that could develop in fuel tanks of various shapes and sizes have been made.

For example, taking fuel treated with additive and considering de-aeration to occur at 30,000 ft. altitude, it has been calculated that a voltage of about 4,000 volts could be attained in a single compartment of about 120 gallons capacity in a wing tank of a typical large aircraft. The energy of discharge from a point in the foam would be of the order $1{\cdot}5 \times 10^{-4}$ Joules, *i.e.* less than the minimum level required for ignition.

This is the extreme case. With an untreated fuel, as mentioned above, the total charge developed is some fourteen times less. But the presence of an active additive in a fuel also increases the conductivity. With the particular additive to which these figures refer, the conductivity of the fuel is some four times the conductivity of an untreated fuel. The voltage developed with the untreated fuel will not therefore be fourteen times less than the above estimates.

It is calculated that untreated fuel will give a voltage about five-and-a-half times less than the above figure, and an energy thirty times less. There is thus a "factor of safety" with untreated fuels of at least 60.

The figure of 3×10^{-4} Joules taken from published work actually applies to propane at the optimum concentration in a 35/65 oxygen-nitrogen mixture at 0·35 atm. pressure. No quantitative information on the minimum ignition energy of kerosine foams is available, but it is likely to be higher than for gaseous mixtures since some of the spark energy must be used up in evaporating part of the fuel before combustion can take place. There is, therefore, a further factor of safety here, of unknown amount, and possibly substantial.

One might expect therefore that the electrostatic charging during de-aeration of present-day fuels in existing and proposed aircraft, is too low to be hazardous by a factor of well over 100.

The reservation must be made, however, that there are circumstances which in combination might reduce this large margin of safety. These are: the presence of traces of electrically-active material in fuel, the presence of an ice haze in the fuel at the time of de-aeration, and the delay of de-aeration until very high altitudes are reached. There is no guarantee that the most potent substances for rendering the fuel electrically active have been examined.

It is desirable therefore to consider methods of ensuring safety that overcome any doubts implicit in this reservation. There are two.

The production of inflammable foams, and especially the production of electrical charge, depends upon a fairly violent foaming process. If the air can be induced to leave the fuel quietly so that little supersaturation occurs, then any question of ignition will completely disappear. An extremely simple way of achieving this object would be to keep booster pumps running in every fuel tank during the whole time from take-off to the end of climb.

An alternative method of reducing the hazard would be to alter the conductivity of the fuel. The voltage developed depends to a large extent upon the leakage through the fuel, in such a way that an increase in conductivity results in a decrease in the voltage, and hence a lesser likelihood of ignition. This increase in conductivity could be achieved by adding to the fuel traces of certain materials. An antistatic additive has been developed to achieve protection from electrostatic charging when handling petroleum products in the refinery. It would be equally effective in this application if deemed necessary.

Summarised Conclusions

For convenience, the conclusions drawn from the investigation are summarised as follows:—

1. The process of liberation of dissolved air from kerosine at moderate altitudes and above can produce inflammable foams. The same process of air liberation can also produce an accumulation of electric charge in foam layers.
2. The electrical charge accumulation is increased in varying degrees by the following factors:—
   (*a*) the presence in the fuel of minute traces of electrically active materials (such materials might be present as corrosion inhibitors added to prevent corrosion in long pipelines).
   (*b*) the presence of an ice haze in the fuel when de-aeration occurs.
   (*c*) the delaying of de-aeration until very high altitudes, say, over 40,000 ft. are reached.
3. Aviation turbine fuels currently used for civil purposes do not contain corrosion inhibitors and, even allowing for the presence of ice haze in the fuel, the charge formed in present-day aircraft is almost certainly insufficient for there to be any likelihood of ignition. However, in future aircraft and operations, attention should be given to these points as it is possible that a combination of two or more factors might increase the charging significantly.
4. One obvious method of avoiding any possible risk is to operate booster pumps during the whole of the time from take-off to the end of climb to maximum flight altitude.

ACKNOWLEDGMENTS

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*loc. cit.

Basic Principles of Radar

With Particular Reference to Aircraft and Missile Applications

*(An Introductory Lecture for Non-Specialists)**

by

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SUMMARY: Modern radar techniques have found wide application in the fields of aeronautics and guided missiles and to make full use of these techniques the designer of modern aircraft and missile systems requires a knowledge of the basic radar principles. This paper is an introduction to these principles. Four main functions of radar are discussed, namely the detection of objects in the beam, measurement of range, information on direction, and the use of the doppler principle to measure velocity and to distinguish moving objects. The discussion is confined to primary or self-contained radars although the principles are applicable to navigation aids such as Gee and Loran. The paper concludes with a brief description of the radome problem.

1. Introduction

The development of radar can be traced back to the 1920s when Appleton and others obtained echoes from the ionosphere and measured the height of the reflecting layers by observing the delay time. The military implications of this were soon realised and by the outbreak of war most of the coastline of Britain was guarded by a chain of ground radar stations capable of detecting approaching aircraft, measuring their range with reasonable accuracy and giving a rough indication of bearing and height. The first airborne radar sets appeared in the early months of the war when night fighter Blenheims and, later, Beaufighters used an early form of AI (Aircraft Interception) to help find the target at night and when Wellingtons of Coastal Command were equipped with ASV (Anti-Surface Vessel). In those early days the impact of radar on the design of aircraft was small. Space could usually be found for the units, there was no pressure cabin to embarrass the installation and aircraft speeds were sufficiently low that external aerials could be tolerated. However, the advent of microwave radar led to the possibility of narrow beams which could be scanned by rotating the aerial and space and a suitable view had to be found inside the aircraft structure for it. At the same time as aircraft performance was increasing, self contained navigation, bombing and interception radars were being developed. The aircraft designer had to take account of these developments, as also the equipment designer had to learn to live with the more stringent environmental conditions in aircraft. The advent of the guided missile was a further step in this evolution. Since then, the scope and applications of radar systems has increased so much that it is probably true to say that no aircraft or missile system today is complete unless its designer has considered in what way radar can assist in solving his problems. It is from this viewpoint that we shall consider the subject of this paper. Because of the wide range of applications of radar it will be necessary to restrict the remarks to basic principles only. No attempt will be made to study any system in detail and in addition nothing will be said about navigation aids such as Gee, Decca and the various forms of Loran. Instead only the principles of primary or self-contained radars will be discussed although, of course, many of the remarks will apply to other systems.

A modern primary radar can fulfil some or all of four main functions. These are:

(*a*) Detection of an object in its beam.
(*b*) Measurement of range.
(*c*) Direction information.
(*d*) Indication of velocity.

The design of an individual radar system will depend upon which of these facilities it should provide, upon the accuracy required and upon the complexity of equipment and operation which can be allowed. These four functions will be discussed in turn.

2. Detection

With few exceptions any object in the beam of a radar will reflect some energy back in the direction of the radar. This echo, which is usually small, is amplified in the receiver and used to provide the information required. In an early warning or airborne search radar the chief requirement is usually for the maximum detection range possible and this will depend

*The Tenth lecture given to the Astronautics and Guided Flight Section of the Society—on 27th April 1959.

upon a number of factors which are best considered by reference to the radar equation [1]:

$$R^4 \text{ proportional to } P_T G^2 \lambda^2 \sigma A_T / P_R \quad . \quad . \quad (1)$$

where R is the maximum range,
P_T is the mean power of the transmitter,
G is the aerial gain, assuming a common aerial for transmission and reception,
λ is the wavelength,
σ is a term representing the attenuation of the atmosphere,
A_T is the target echoing area—a measure of the fraction of the radiation incident on the target which is reflected back in the direction of the radar,
P_R is the minimum detectable signal.

It will be seen that for the maximum range of detection the mean power of the transmitter (P_T) should be as high as space, weight, power supplies and so on, will allow but that the range increases only as the fourth root of P_T.

A more powerful factor is the aerial gain (G) since this enters the equation in both transmitting and receiving conditions, assuming a common aerial for both. Where separate aerials of gains G_T and G_R are used the term G^2 is replaced by $G_T G_R$. The aerial gain (G) is proportional to the area of the radiating aperture in square wavelengths and thus for any given wavelength the aerial should be as large as is practicable. For a given aerial size the term $G^2\lambda^2$ is proportional to $1/\lambda^2$ and thus for maximum range the shortest possible wavelength should be used. However, at wavelengths less than about 3 cm. the oxygen and water vapour in the atmosphere attenuates the signal to an extent dependent upon the wavelength and the content of oxygen and water vapour in the path concerned[2]. Fig. 1 is a plot of attenuation as a function of wavelength for a propagation path wholly at sea level at 20°C with a water vapour content of 10 gm./m^3. At higher altitudes the water vapour content is much less and the attenuation consequently reduced so that in the detection of high flying aircraft or in AI operations at altitude this effect is not so serious.

At the shorter wavelengths a number of physical problems limit the performance. The mechanical tolerances in the manufacture of components, valves and aerial are proportional to wavelength and thus become increasingly tighter and more difficult to achieve as the wavelength is reduced. Transmitters are less efficient. Waveguide, which is used to transmit the microwave energy from one circuit to another and from the transmitter-receiver to the aerial has greater loss. In addition its size is directly related to the wavelength so that at short wavelengths it is physically small and can not carry intense fields without high pressurisation.

When the radar energy falls upon an object in the beam it is in general reflected in all directions but it is only the reflection back in the direction of the receiving aerials which is of importance to the radar system. If the reflecting object has smooth surfaces, infinitely large compared with a wavelength, specular reflection takes place, *i.e.* the angle of reflection is equal to the angle

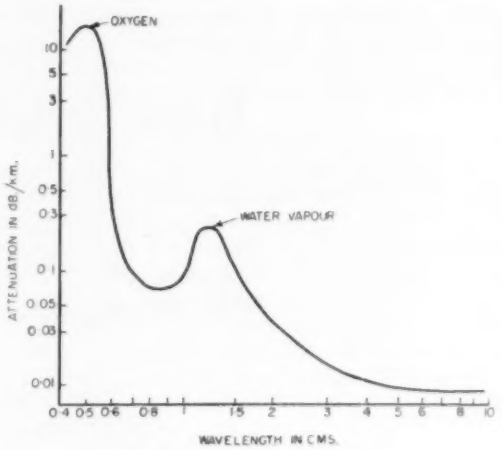

FIGURE 1. Atmospheric attenuation.

of incidence, so that no energy returns to the radar unless it is in a direction normal to the surface. Thus no radar echo is received from a perfectly smooth sea or inland waterway except from vertically above it. If the target has smooth surfaces many wavelengths in dimension, these behave like a radiating aperture and have many sidelobes, so that the amplitude of the echo will depend upon the exact position of the radar relative to the surface and will fluctuate wildly as the target approaches the radar. When the surface of the target is rough at the wavelength in use *e.g.* fields, trees, ripples on the sea, the back-scatter is a more slowly varying function of the angle of incidence of the radar[3].

It is found in practice that the echo from a modern high performance aircraft tends to be localised to a few parts of the structure, for example, the air intakes in jet aircraft. The result is that interference takes place between the echoes from those reflecting areas and the mean position of the aircraft echo changes wildly with aspect; this phenomenon is known as "glint"[4] and makes the performance of a homing eye at close range unpredictable.

It will be seen that in practice the value of the factor A_T in the radar equation at any particular instant is not very predictable, although as a result of much careful measurement it is possible to quote mean values for any particular target. However, reference to the radar equation shows that although the received signal power is linearly related to the echoing area (A_T), the maximum range of detection varies as only the fourth root of A_T and a reasonable assessment of maximum range is possible.

The limiting factor in the range performance of the radar is the random variations in voltage occurring in the early stages of the receiver, usually referred to as receiver noise. For a signal to be visible to the operator or usable in a control loop it must in practice be several times greater than the noise in the display or circuit in question[5]. The exact factor is a complex function of several parameters including the type of display, viewing conditions, the skill of the operator and the rate of scan if the aerial is made to rotate.

An upper limit of range is always set by the radar

horizon. At the shorter wavelengths usually used for radar the change with height in the refractive index of the atmosphere guides the waves to some extent round the earth's surface and in practice it is usually assumed that the radar horizon can be calculated by taking the radius of the earth to be 4/3 of its actual value[6]. The range of detection of low-flying aircraft will more usually be limited by the radar horizon than by signal to noise conditions in the receiver. In practice, ground reflections also add to the problem of detecting the low flier, although as will be seen later these can be reduced to some extent by velocity discrimination.

3. Range

The second facility which a radar can be designed to provide is that of measurement of range. To do this the transmitter provides short sharp pulses of high intensity and the time delay between the transmission of each of these and the receipt of the echo can be measured on a cathode ray tube display. The time intervals involved are small, being about $12{\cdot}5 \times 10^{-6}$ seconds per nautical mile of range. In the P.P.I. (Plan Position Indicator) the spot is moved outwards from the centre of the tube along a line representing the direction of the radar beam, the start of the trace being coincident in time with the transmitter pulse. The output from the receiver is used to modulate the beam so that echoes appear as bright spots on the trace and their distance from the centre is a measure of the range of the target. The delay time is proportional to the straight line distance from the radar to the target (slant range) and, for this display to give a true indication of plan position, correction must be made for the difference in height between target and radar. If the radar is used to provide a navigation display in an aircraft, the targets being different points on the ground, this height difference is known to some accuracy and the cathode ray tube beam can be made to scan across the tube according to the correct hyperbolic law:

$$x = K\left[(\tfrac{1}{2}ct)^2 - H^2\right]^{\frac{1}{2}}$$

where x is the distance of the spot from the centre at time t measured from the instant of transmission, c is the velocity of electromagnetic waves, H is the height, and K is a scale factor.

The time base on the tube is made to rotate in synchronism with the rotation of the radar beam and builds up a map of the ground around the aircraft with the present position of the aircraft in the centre. It is also possible to stabilise this map against aircraft motion by suitably biassing the deflection of the beam of the cathode ray tube so that the aircraft appears to move across a stationary map.

The width of the echo from a single point target is the same as that of the transmitted pulse and this sets a limit to the accuracy of range measurement and also to the ability to resolve two adjacent targets. The narrower the pulse the greater is the accuracy and the higher the resolving power. There is a clash here between the requirements of maximum detection range and resolving power. In practice the transmitter peak power, *i.e.* the power level radiated during the pulse, is limited by the choice of valve so that for a given mean power the radar designer can choose between a few wide pulses and a lot of narrow pulses per second.

$$P_T = P_p F T \quad . \quad . \quad . \quad . \quad (2)$$

where P_T mean power transmitted
P_p peak power in the pulse
F number of pulses per second
T pulse width

The integration or summing of the received energy is more efficient if carried out before the pulse envelope is derived (*i.e.* predetector) rather than after, so that in a conventional radar receiver the signal-to-noise ratio for a given mean signal power is higher for wide pulses than for narrow ones. Thus in an early warning radar where maximum range is the prime requirement a wide pulse is used while an airborne navigation radar uses narrow pulses to give as high resolution as possible. In practice the pulse widths used lie between 0·1 and 10 microseconds.

Another factor in the choice of pulse rate and pulse width is the possibility of range ambiguity. Referring to equation (2), the spacing between pulses is $1/F$ seconds and this corresponds in time to the echo from an object at a distance $c/2F$ where c is the velocity of electromagnetic radiation. Thus echoes from objects at a range R greater than $c/2F$ will be confused with those at a range $R - c/2F$ corresponding to the next transmitted pulse. This is another reason why a long range early warning radar uses a low pulse repetition rate (F).

It is clearly desirable to be able to use the same aerial for both transmitting and receiving and in a pulse radar this is achieved by an RF switch called a duplexer. The switch has to ensure that during the transmitting period very little of the transmitter power goes to the receiver where it would burn out the mixer crystal and during reception no appreciable power is lost in the transmitter. Fig. 2 shows a modern microwave

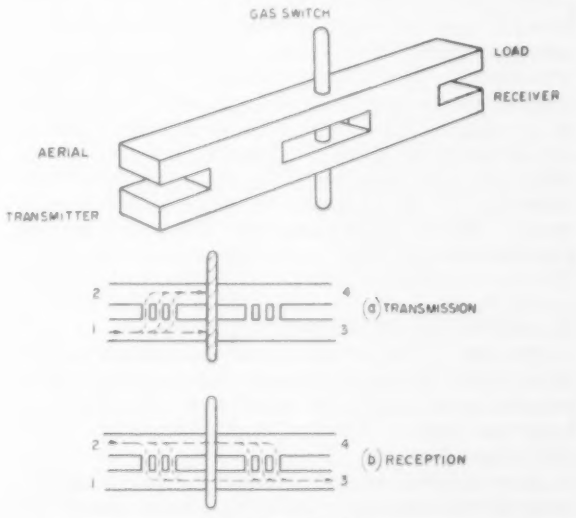

FIGURE 2. Duplexer.

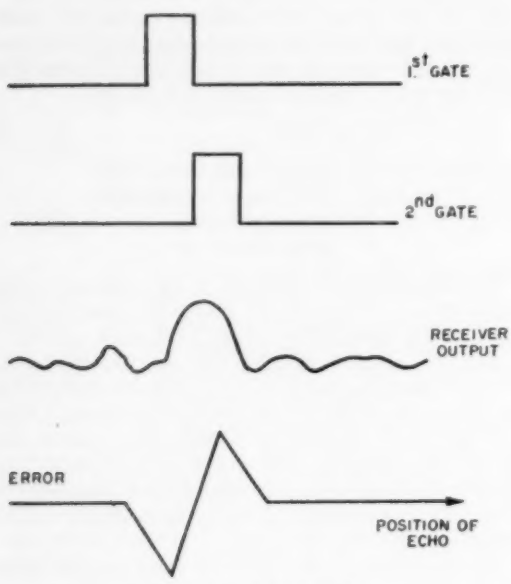

FIGURE 3. Range strobe.

duplexer. During the transmitting period the energy from the transmitter enters at port 1 and is split into two equal quadrature signals by the slot coupler. The field is sufficiently intense to ionise the gas switch which then appears as a mirror to the incident energy and reflects it. The path lengths are such that the two waves after reflection re-combine in the upper arm and the energy goes out to the aerial via port 2. In the receive condition the signals which enter at port 2 are split by the coupler as before but are no longer strong enough to ionise the gas switch and so re-combine in port 3 whence they pass to the mixer units in the receiver.

In a tracking radar used for following specific targets, it is usually necessary to be able to isolate the returns from one particular target to derive bearing and possibly velocity information and a circuit known as a strobe is used to do this. This circuit also gives an accurate measure of range. Fig. 3 illustrates the action of a strobe. Two adjacent gates are derived whose position relative to the transmitter pulse is controlled by a voltage. These are used to sample the receiver output, the signal in one is subtracted from that in the other and an error output voltage derived which is zero when the two gates straddle the target and is proportional to error if the target moves. This can be used as the error sensing element in a servo-mechanism.

4. Direction Information

A radar can be made to give information on the direction of an echoing object by confining the transmitted energy to a narrow beam and using the same beam for reception. It must then be possible to steer the beam at the target.

In an airborne navigation radar it is usually required to make the beam as narrow as possible since this increases the resolution. In a search radar resolution is also important but a beam which is too narrow and made to scan a large sector rapidly results in only a few pulses from each target per scan. This increases the problem of deciding whether any particular signal in the receiver output is a peak of noise or a genuine echo and this effectively reduces the maximum range since the number of false alarms must be strictly limited.

It is fundamental that the beamwidth is proportional to λ/A where λ is the wavelength and A the linear dimension (aperture) of the aerial in that plane. We have discussed some of the points concerned in the choice of wavelength. For high resolution on a given wavelength a large value of A is required; for example at 3 cm. an aperture of 6 ft. produces a 1° beam. In a practical world, and in particular in an aircraft, the value of A is likely to be limited by physical conditions and beams narrower than a degree or so are difficult to realise.

In most radars it is important that the energy be limited to a single beam and the amount radiated in side lobes be reduced to a minimum. The detailed shape of the polar diagram of the aerial, *i.e.* the graph of field strength as a function of angle, is determined by the amplitude and phase of the electric field across the radiating aperture. For narrow beam radars it is in fact the Fourier transform of this aperture distribution and it is the control of this distribution that the designer uses to design his aerial system. A simple narrow beam can be obtained either by feeding a parabolic reflector from a single horn feed at its focus or by cutting slots at approximately half-wavelength intervals in a length of waveguide (*see* Fig. 4). In the former the amplitude and phase distribution across the aperture of the dish is largely determined by the characteristics of the feed horn and in the latter by the dimensions, position and angle of the individual slots.

In some applications, *e.g.* early warning ground radar and airborne navigation radar, it is an advantage to design the polar diagram of the aerial in the vertical plane so that a target of constant echoing area produces the same amplitude of echo in the receiver at all relevant

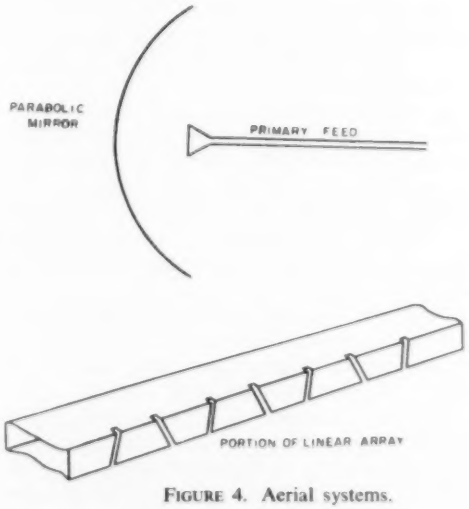

FIGURE 4. Aerial systems.

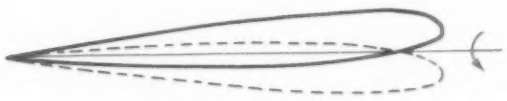

FIGURE 5. Conical scan.

ranges. At a given altitude H the slant range R and depression or elevation angle θ are related by $R = H \operatorname{cosec} \theta$. From the radar equation the received power is proportional to $1/R^4$, *i.e.* to $1/\operatorname{cosec}^4 \theta$. Since the aerial diagram enters the equation in both transmitting and receiving functions the required diagram law is "power proportional to $\operatorname{cosec}^2 \theta$" or "field strength to $\operatorname{cosec} \theta$". An approximation to this can be obtained by careful design of the shape of the reflector in this plane. If a linear array is used to shape the beam in the horizontal plane it is convenient to use this as the primary feed to a reflector which shapes the vertical diagram.

The scanning of the beam is usually achieved by rotation of the whole aerial although over a limited angle of scan there are other possibilities. For example if a constant phase shift can be introduced between each radiating slot of a linear array this will squint the beam. This could be achieved either by the use of ferrites or by changing the frequency. For example a fractional change α in frequency corresponds to a shift in the direction of the beam of about $1{\cdot}5\,\alpha$ radians.

In some radars, *e.g.* tracking radars or homing eyes in missiles, it is necessary to derive error signals to enable the beam to be kept on the target by means of a servo-mechanism. This can be achieved in one of two ways. If a dish is fed by a simple radiating dipole positioned slightly off axis the axis of the beam is displaced from the mechanical axis of the dish. If this dipole is now made to nutate around the mechanical axis the beam also rotates about this axis (*see* Fig. 5). From a target on axis the strength of the echo is constant for all positions of the beam. For a target off axis, however, the echo strength is modulated at the frequency of rotation of the dipole and the amplitude of this modulation is a measure of the angular displacement of the target from the axis while its phase

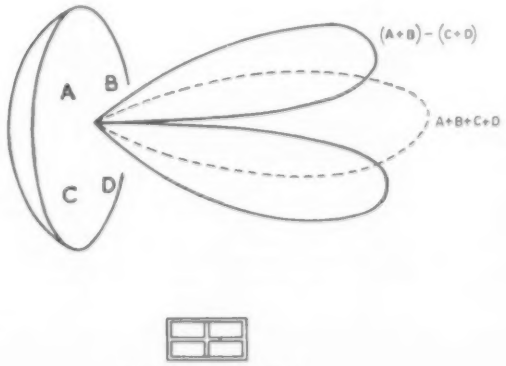

FIGURE 6. Static split system.

relative to some convenient reference gives its position in elevation and azimuth. This signal can then be used as the required error signal in the servo. This method is known as conical scan. Another method is the static split system in which the dish is fed from four small horns each displaced from the mechanical axis, one in each quadrant. Each horn produces a beam which is slightly off axis. For transmission the four horns are fed in phase to produce a conventional pencil beam; on reception they are combined to produce the sum signal $A+B+C+D$ and difference signals of the form $(A+B)-(C+D)$, (*see* Fig. 6). The amplitude of the difference signal is approximately proportional to the angular displacement off axis and phase comparison with the sum signal gives the sign of this error.

5. Velocity

A radar provides direct information on velocity by use of the doppler principle in which velocity can be derived from the rate of change in the phase of the echo when referred to the transmitted signal. If the transmitted signal is $\cos 2\pi f_o t$ and the range of the target is R the echo on arrival at the receiver is proportional to $\cos(2\pi f_o t - \frac{4\pi R}{\lambda})$. If the radial velocity of the target is V the echo varies as $\cos[2\pi(f_o + \frac{2V}{\lambda})t + \beta]$ and thus has an apparent frequency shift, the doppler frequency, of $2V/\lambda$. To obtain this doppler frequency a signal of the form $\cos 2\pi f_o t$ must be available in the receiver when the echo arrives. In a continuous wave (CW) system the master CW source provides this signal and the doppler signal is obtained by beating the echo with the CW source. The doppler frequency is relatively small, for example at S band (3,000 Mc./sec.; $\lambda = 10$ cm.) it is 10 c./sec. per knot of radial speed, and it is apparent that high frequency stability is required. In a conventional pulsed magnetron system the phase of the start of the oscillation in each pulse is random and the reference is provided by phase locking another oscillator to each transmitted pulse. In some applications it is possible to use as the phase reference ground returns at the same range as the target, particularly when it is desired to discriminate echoes from targets moving relative to the ground.

The use of the doppler principle is increasing but only two applications will be discussed here. The first is a method of reducing the relatively large echoes received from local terrain in a ground radar. These are usually sufficiently large to swamp target echoes particularly at the shorter ranges and have constituted a major problem to the radar operator since its inception. It is possible to discriminate against this ground clutter by using the fact that it has little or no relative motion and hence no doppler frequency shift in the echo, while the target echo has a measurable doppler frequency. If the ground clutter at a particular range is compared in phase with the reference signal the amplitude of the pulses obtained is relatively constant (*see* Fig. 7). If a target echo is so treated the pulses are modulated at the doppler frequency of the target. Thus

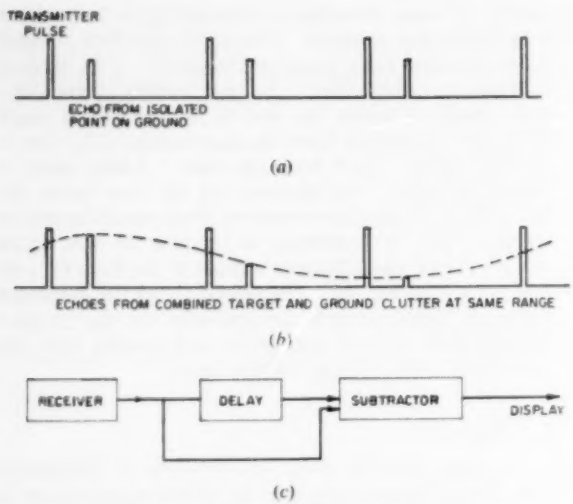

FIGURE 7. Simple M.T.I. system.

at ranges where there is a target echo combined with clutter the pulses are modulated as shown in Fig. 7(*b*). If now a circuit (Fig. 7(*c*)) is arranged which delays the receiver output one pulse repetition period and then subtracts it from the receiver output at that instant there will be no output from the clutter but some output if a moving target is present. This can then be painted on the display. This system is known for obvious reasons as M.T.I. (moving target indication).

Two main difficulties are immediately apparent. As the narrow radar beam is made to rotate it will modulate the echoes from a given piece of ground at a rate dependent upon the number of pulses which a given point receives as the beam scans through it. This will give an output in the subtraction unit which will then paint on the display. Thus a narrow beam and a fast scan rate are incompatible with successful M.T.I. This can be alleviated to some extent by more elaborate cancellation systems using several consecutive pulses but the complexity of the equipment is considerably increased.

Secondly it can be seen that if the doppler frequency of the target is close to the pulse repetition frequency or a harmonic of it the amplitudes of the echoes after phase comparison will be constant or slowly changing and they will be cancelled by the subtraction circuit. There are thus gaps in the cover at doppler frequencies which are multiples of the pulse repetition frequency. For example in an S band radar (for which the doppler frequency is 10 c./sec. per knot) operating at a pulse rate of 500 per second, the first "blind velocity" is 50 knots and there are others at multiples of 50 knots. If the spacing between successive transmitter pulses is made to vary, this can to some extent be overcome, but since the delay circuit must alter its delay to match the transmitter pulse spacing the additional complexity can be envisaged.

Another very important application of the doppler principle is the doppler navigation system[7]. If energy is transmitted in a narrow beam from an aircraft in flight (*see* Fig. 8) there will be a doppler shift in the frequency of the echo from the ground of $(2V \cos\theta)/\lambda$ cycles per second where V is the aircraft speed and θ the angle between the beam and the flight path of the aircraft. This gives an accurate measure of the ground speed of the aircraft. To detect this doppler frequency the phase of the transmitted signal must be remembered and a convenient way of doing this is to transmit in two beams simultaneously, one facing forward and the other aft, at the same angle of depression. The frequency of the signals in the forward beam is the $(2V \cos\theta)/\lambda$ cycles per second above the original transmitted frequency, and that in the aft beam is the same amount below the original frequency. Thus the beat frequency between the two beams is $(4V \cos\theta)/\lambda$. Such a system is called a Janus system, from the god of time who had two heads, one to look forward to the future and one to look back at the past. The method of deriving the ground speed is the frequency equivalent of a range strobe. Two phonic wheels on one shaft give slightly different frequencies proportional to the speed of rotation of the shaft. These are compared with the frequency of the received doppler beat and an error signal derived which is used to control the speed of rotation of the shaft so that the frequencies of the phonic wheels straddle the doppler beat frequency.

The system so far outlined will measure the speed of the aircraft in a direction given by the line joining the two beams on the ground. It is clear that if a further two beams are used in some other direction it will be possible to obtain the velocity vector in the horizontal plane and hence measure the drift. The

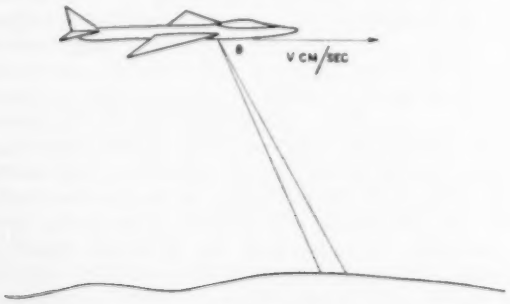

FIGURE 8.

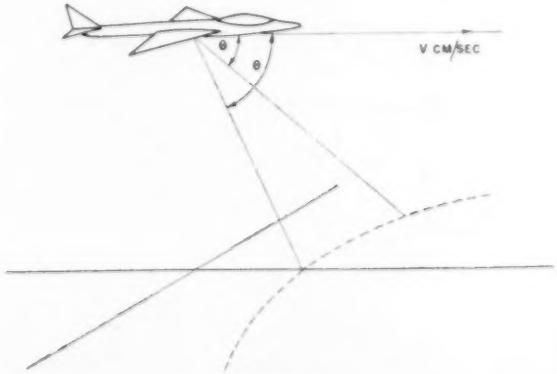

FIGURE 9.

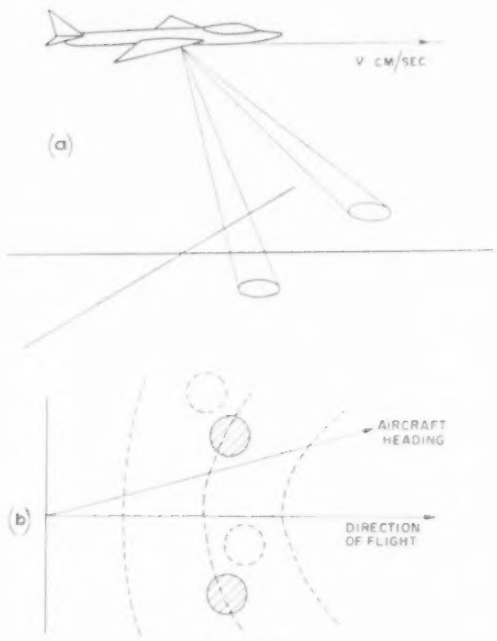

FIGURE 10.

dotted line in Fig. 9 shows the locus of points on the ground having the same doppler frequency. In Fig. 10(*b*) the circles show the intersection on the ground of the two forward facing beams of Fig. 10(*a*) and the dotted lines the contours of constant doppler frequency. The positions of the shaded circles show that when there is no drift the frequency in each beam is the same; however when drift is present (dotted circles in Fig. 10) the frequency in one beam increases while that in the other decreases. Consider now two Janus systems (Fig. 11). The beat frequency given by the pair of beams A, A' is lower than that for the pair B, B'. If now these

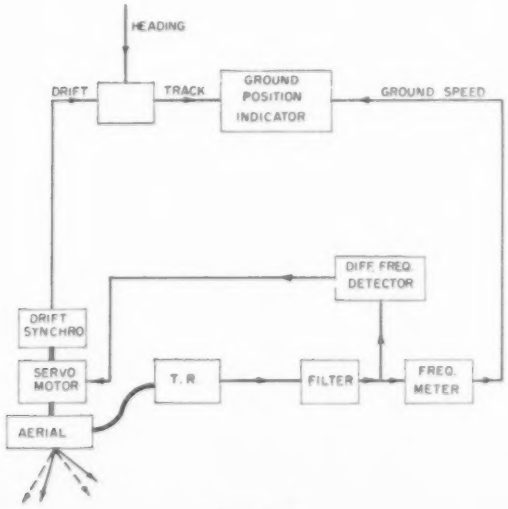

FIGURE 12.

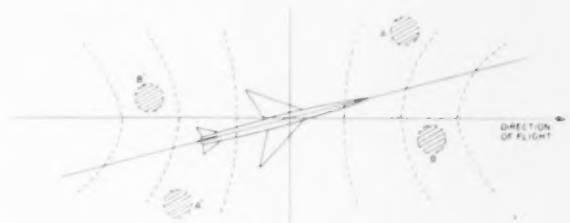

FIGURE 11.

two frequencies are compared in a discriminator which gives an error signal proportional to their difference, a servo system can be designed which rotates the whole structure containing the aerial system to zero this difference frequency. The aerial is then aligned along the direction of flight and the angle between this and the axis of the aircraft gives the drift angle. This drift angle can be combined with heading from the aircraft's compass to give track angle and together with ground speed they form the basic inputs to a D.R. system (Fig. 12).

6. Radomes

Before closing, it is appropriate to say a few words about radomes. The problem of designing a window arises from the fact that when radiation passes from one medium to another of different refractive index not all the incident radiation passes into the new medium but some is reflected at the interface. This effect can be reduced either by making the window half a wavelength thick or electrically very thin. An example of the latter is a sandwich in which the inner core is a honeycomb structure whose refractive index is approximately unity while the outer skins are thin and merely provide a good mechanical surface; electrically the skins have negligible effect. Using these techniques it is relatively simple to

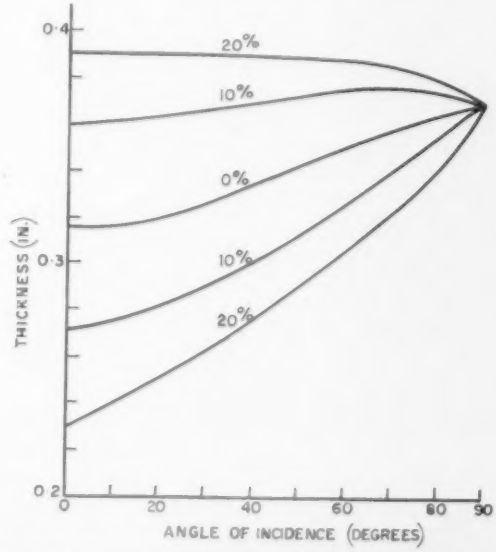

FIGURE 13. Power reflection for half-wave sheet at X band.

design[9] a satisfactory radome which will operate over a limited frequency band when the rays pass through at nearly normal incidence. The problems arise when a wide range of angles of incidence is involved, as, for example, in the nose radome of a missile or A.I. aircraft in which angles of incidence up to 70°-80° can be encountered. Two electrical considerations are involved in the design of the radome, (*a*) there must be negligible attenuation of the wave passing through the radome, and (*b*) the aberration, *i.e.* the deflection of the beam, must be as low as possible. In addition, of course, the radome must usually be structurally strong, light and resistant to rain erosion, moisture and high temperature. Fig. 13 shows contours of constant power reflection as a function of the thickness of flat sheets and of angle of incidence for a material of dielectric constant, ε, of 4, and illustrates the problems of the electrical design. It will be seen that if the radome is to operate satisfactorily over a wide range of angles of incidence, there is a very tight tolerance on the thickness and this must be maintained in production and also over the range of temperatures in operation.

7. Conclusion

A paper of this length on such a wide subject can only serve as an introduction and it is inevitable that the aspects discussed have received all too meagre treatment and much has been omitted. Nor must it be assumed that we are at the end of the road in radar design. New advances in physics lead to more refined radar techniques and the application of these techniques to more problems. It is only by maintaining the widest knowledge of these techniques that we can ensure that the full capabilities of radar are realised.

ACKNOWLEDGMENTS

The author is indebted to his colleagues at R.R.E. for their willing assistance in the preparation of the paper.

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SUMMARY OF DISCUSSION

by

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In the lively discussion which arose following the paper, the comments and questions revealed what the non-specialist considered the blackest mysteries of the radar art. It was generally agreed that the jargon of the radar designer with his " db.s, glint and clutter " helped to create the mystery but that this was the same in all specialised fields.

A number of questions arising from the paper were concerned with continuous wave doppler systems. Mr. Boardman, in his reply, described in more detail various technical points concerned with doppler navigation. On the increasing use of continuous wave techniques for tracking radars he stated that they enabled target echoes to be distinguished from ground returns and although, in theory, their range performance was no greater than could be obtained from a pulsed radar, it was in practice slightly superior.

Some speakers were concerned with the "plumbing" used to carry micro-wave signals but it was explained that ordinary mains flex would not be suitable. At very high frequencies the electric currents would not be evenly distributed through the conductor but, instead, would collect near the surface. This increased the effective resistance per unit length and, hence, increased the losses. The author observed that transmission of power along a waveguide was controlled radiation rather than conduction.

In reply to those speakers who found the ubiquitous term "noise" difficult to understand, it was explained that apart from thermal noise there were fluctuations in the amplitude of target echoes which degraded the performance of radars. This applied both to reflections from aircraft targets and reflections from the ground, as in the case of navigation radars. There was very little that could be done to reduce the effects of this.

The Chairman (Sir George Gardner) in his closing remarks congratulated the lecturer on his lucid address and his careful avoidance of too many colloquial terms.

TECHNICAL NOTES

*Pressure Loss Data for Crimped Metal Strip Matrices**

by

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(Formerly Project Engineer, Hawker Siddeley Nuclear Power Company, Langley, now C. A. Parsons and Co. Ltd., Nuclear Research Centre, Newcastle upon Tyne)

DATA WERE OBTAINED of the pressure loss characteristics of metal strip matrices constructed by winding together alternate layers of crimped and plain metal strip. The hydraulic diameters of the passages so formed were in the range 0·023 in. to 0·060 in. with passage lengths from 1 in. to 6 in. and metal thickness from 0·002 in. to 0·006 in.

The units were mounted in a 6 in. diameter duct in which air velocities of up to 200 ft./sec. were obtained. The range of passage Reynolds number was from 300 to 6,000. The majority of the experimental results were for atmospheric pressure, but some tests were carried out at sub-atmospheric pressures to test a correlation equation derived from analysis of the results.

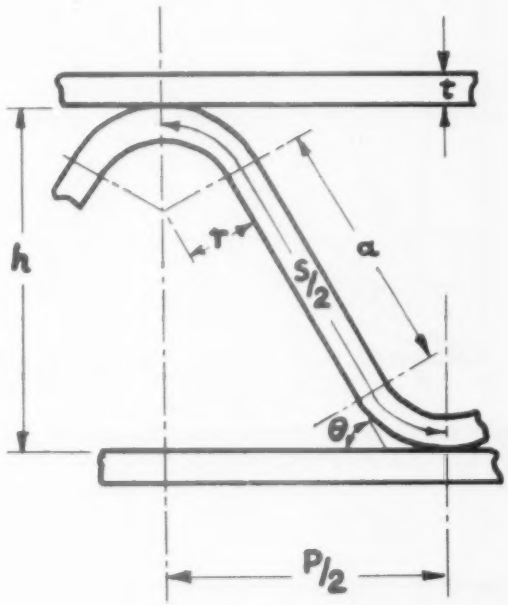
NOTATION

Reference should be made to Fig. 1 which shows the form of the matrix.

l	length of passage
h	dimension of passage
d_e	hydraulic diameter
t	wall thickness
θ	angle of inclination of passage side
B	blockage ratio of matrix
r	apex radius
a	length of passage side
P	pitch of passages
S	perimeter of crimped material per passage
p	wetted perimeter per passage
A	wetted area per passage
C	flow area per passage
N	number of passages per unit frontal area
F	length of metal strip per unit frontal area
A_m	wetted area per unit frontal area
W	weight per unit frontal area
ρ	density of air
V	mean velocity in matrix passage
f	friction factor
Δp	pressure differential across matrix
Re	Reynolds number
μ	viscosity of air
A_1, A_2, A_3	constants in correlating equation

1. PRESSURE LOSS CHARACTERISTICS

The various parameters of the 33 different units are listed in Table I. Figs. 2 to 5 show the pressure loss characteristics as a function of the bulk mean velocity of air in the 6 in. duct. All the materials were rolled strip and great care was taken in manufacture to keep the crimp form perpendicular to the edge.



$$a = \frac{h - [2r(1-\cos\theta) + t(2-\cos\theta)]}{\sin\theta} \qquad \frac{S}{P} = \frac{a + \theta(2r+t)}{a\cos\theta + (2r+t)\sin\theta}$$

$$\text{Blockage, } B = \frac{t}{h+t}\left(1 + \frac{S}{P}\right)$$

$$\text{Wetted parameter, } p = 2a + P + 2\theta(2r+t)$$

$$\text{Area per passage, } A = (Ph - St)/2$$

$$\text{Hydraulic diameter, } d_e = 4A/p$$

FIGURE 1. Section of the crimped metal strip matrix and derivation of the geometrical parameters.

2. ANALYSIS OF DATA

The experimental data were re-plotted in non-dimensional form, that is non-dimensional resistance ($\Delta p/\rho V^2$) as a function of the flow parameter, Reynolds number (Re). The density of the air stream was evaluated at the mean pressure in the matrix passages and at the bulk temperature, as was the viscosity in $Re = \rho V d_e/\mu$. The velocity was the mean value in the passage, calculated from data in Table I, except that the blockage used in calculating the velocity in the passages was increased by a factor to allow for supporting structure. This factor was 6·8 per cent for all the units except Nos. 5 and 6, being in these cases 12·0 per cent.

The characteristics, plotted on log-log graph paper were straight lines with a negative gradient up to a certain critical value of Reynolds number, levelling out after passing this value. The gradients of the straight-line part

*The work described in this note was carried out in the Chemical Physics Department, National Gas Turbine Establishment, under an extra-mural contract.

Received 11*th June* 1959.

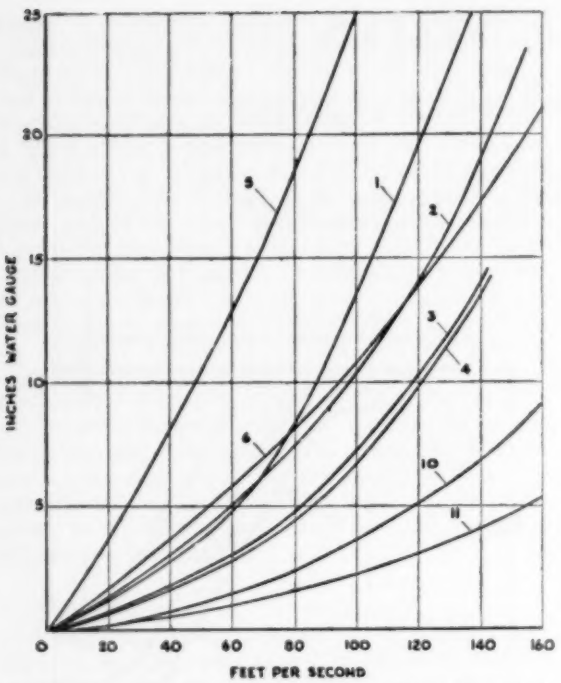


FIGURE 2. Pressure loss characteristics of matrices Nos. 1, 2, 3, 4, 5, 6, 10 and 11.

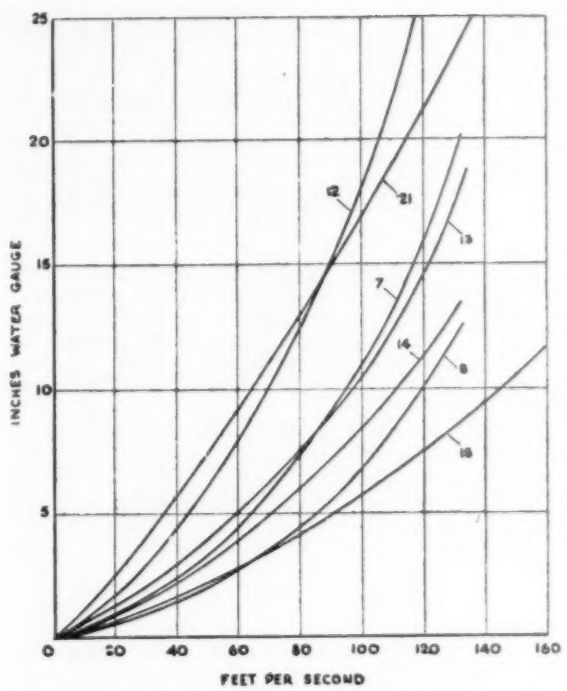


FIGURE 3. Pressure loss characteristics of matrices Nos. 7, 8, 12, 13, 14, 15 and 21.

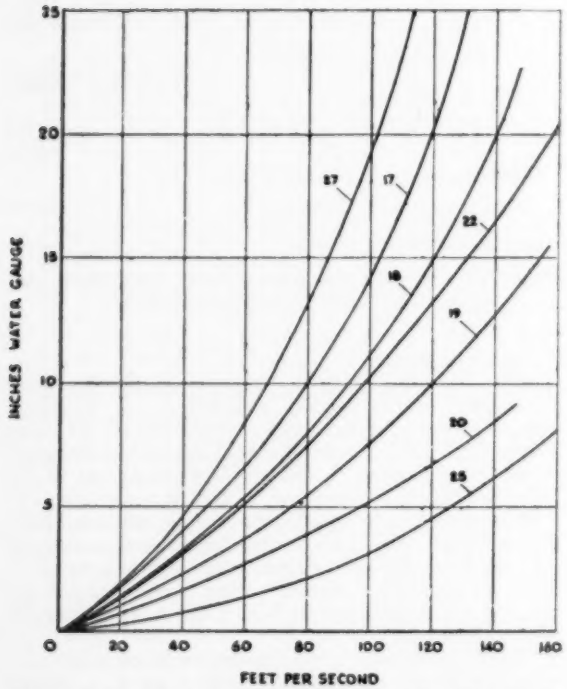


FIGURE 4. Pressure loss characteristics of matrices Nos. 17, 18, 19, 20, 22, 25 and 27

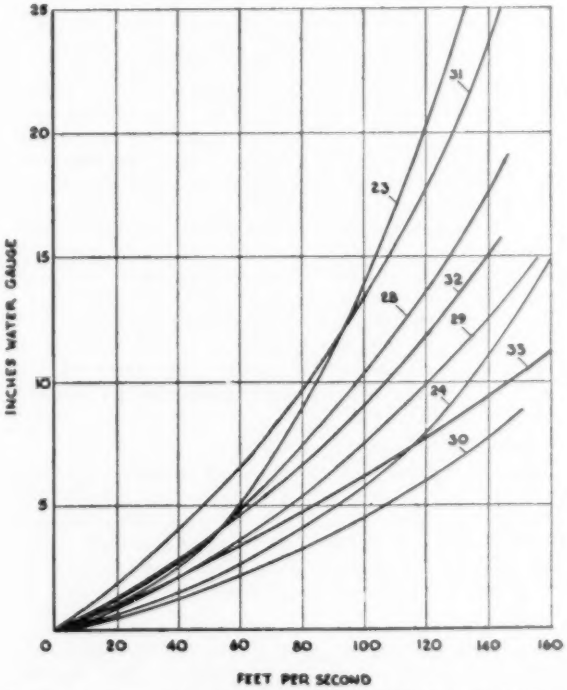


FIGURE 5. Pressure loss characteristics of matrices Nos. 23, 24, 28, 29, 30, 31, 32 and 33.

TABLE 1
GEOMETRICAL PARAMETERS OF THE 33 TEST MATRICES

Specification						Single Passage									Matrix			
No.	*l* in.	*h* in.	*t* in.	θ deg.	*Material*	*r* in.	*a* in.	*P*/2	*S*/*P*	*B* per cent	*Wetted perimeter p* in.	*Wetted area A* in.²	*Cross section C* in.²	*Hydraulic diameter* d_e in.	l/d_e	*No. of passages N* No./in.²	*Length of strip F* in./in.²	*Wetted area* A_m in.²/in.²	*Weight per unit frontal area W* lb./ft.²
1	2·75	0·104	0·006	90	Cu	0·014	0·064	0·034	3·45	24·3	0·248	0·682	0·00285	0·046	60	267	40·5	182	30·7
2	3·9	0·103	0·003	90	Cu	0·015	0·067	0·033	3·60	13·0	0·252	0·982	0·00304	0·048	81	286	43·5	281	23·4
3	2·75	0·067	0·006	53	Cu	0·019	0·044	0·061	1·39	19·6	0·251	0·691	0·00360	0·057	48	224	32·8	155	24·8
4	3·9	0·067	0·003	53	Cu	0·019	0·048	0·061	1·39	10·2	0·256	1·00	0·00385	0·060	65	233	34·1	233	18·3
5	3	0·025	0·0021	45	Cu-Ni	0·015	0·019	0·036	1·23	17·3	0·138	0·414	0·00081	0·024	127	1022	82·3	423	23·7
6	1	0·025	0·0021	45	Cu-Ni	0·015	0·019	0·036	1·23	17·3	0·138	0·138	0·00081	0·024	42	1022	82·3	141	7·9
7	6	0·073	0·0029	60	Cu-Ni	0·013	0·064	0·057	1·65	10·1	0·279	1·675	0·00388	0·056	108	231	34·9	387	27·8
8	4	0·076	0·00295	60	Cu-Ni	0·013	0·068	0·059	1·66	9·9	0·290	1·158	0·00418	0·058	69	215	33·7	249	18·2
9	3	0·077	0·00295	60	Cu-Ni	0·013	0·069	0·059	1·67	9·8	0·293	0·880	0·00428	0·058	51	210	33·4	185	13·8
10	2	0·078	0·0029	60	Cu-Ni	0·013	0·070	0·060	1·68	9·6	0·297	0·593	0·00428	0·059	34	206	33·0	122	8·7
11	1	0·079	0·0028	60	Cu-Ni	0·013	0·071	0·061	1·69	9·2	0·300	0·300	0·00448	0·060	17	201	32·9	60	4·2
12	6	0·058	0·0029	60	Cu-Ni	0·008	0·053	0·043	1·69	12·8	0·214	1·282	0·00227	0·043	141	384	43·7	492	34·8
13	4	0·060	0·00295	60	Cu-Ni	0·008	0·055	0·044	1·70	12·6	0·221	0·884	0·00241	0·044	92	361	42·9	319	23·2
14	3	0·061	0·00295	60	Cu-Ni	0·008	0·056	0·045	1·71	12·5	0·225	0·674	0·00249	0·045	68	352	42·3	237	17·1
15	2	0·063	0·0029	60	Cu-Ni	0·008	0·058	0·046	1·72	12·0	0·231	0·462	0·00265	0·046	44	333	41·3	154	10·9
16	1	0·065	0·0028	60	Cu-Ni	0·008	0·061	0·047	1·72	11·2	0·238	0·238	0·00281	0·047	21	315	40·1	75	5·1
17	4	0·043	0·00295	53	Cu-Ni	0·020	0·029	0·051	1·36	15·1	0·206	0·822	0·00201	0·039	102	423	51·3	348	27·7
18	3	0·043	0·00295	53	Cu-Ni	0·020	0·029	0·051	1·36	15·2	0·206	0·617	0·00201	0·039	77	423	51·3	261	20·8
19	2	0·044	0·0029	53	Cu-Ni	0·020	0·030	0·052	1·37	14·6	0·210	0·419	0·00209	0·040	50	407	50·5	171	13·4
20	1	0·043	0·0028	53	Cu-Ni	0·020	0·029	0·051	1·36	14·4	0·206	0·206	0·00201	0·039	26	423	51·5	88	6·6
21	2	0·028	0·0029	53	Cu-Ni	0·015	0·015	0·035	1·33	21·9	0·135	0·270	0·00087	0·026	78	920	75·5	248	19·4
22	1	0·029	0·0028	53	Cu-Ni	0·015	0·016	0·036	1·34	20·6	0·139	0·139	0·00090	0·026	39	876	73·7	122	9·5
23	6	0·078	0·00385	60	Al	0·012	0·069	0·059	1·67	12·5	0·315	1·83	0·00421	0·054	112	207	32·7	379	10·6
24	3	0·078	0·00385	60	Al	0·010	0·072	0·057	1·78	13·0	0·307	0·919	0·00402	0·053	57	216	34·0	199	5·5
25	2	0·078	0·00385	60	Al	0·010	0·072	0·057	1·78	13·0	0·307	0·613	0·00402	0·053	38	216	34·0	132	3·7
26	1	0·078	0·00385	60	Al	0·010	0·072	0·057	1·78	13·0	0·307	0·306	0·00402	0·053	19	216	34·0	66	1·8
27	6	0·056	0·00385	60	Al	0·009	0·047	0·043	1·64	17·0	0·226	1·358	0·00402	0·040	150	390	44·0	530	14·2
28	3	0·056	0·00385	60	Al	0·007	0·050	0·040	1·70	17·3	0·218	0·654	0·00227	0·041	73	413	45·0	270	7·3
29	2	0·056	0·00385	60	Al	0·007	0·050	0·040	1·70	17·3	0·218	0·436	0·00213	0·041	49	413	45·0	180	4·9
30	1	0·056	0·00385	60	Al	0·007	0·050	0·040	1·70	17·3	0·218	0·218	0·00213	0·041	24	413	45·0	90	2·4
31	3	0·045	0·00385	53	Al	0·018	0·025	0·047	1·32	18·2	0·218	0·655	0·00200	0·037	82	435	47·3	285	7·7
32	2	0·045	0·00385	53	Al	0·018	0·025	0·047	1·32	18·2	0·218	0·436	0·00200	0·037	55	435	47·3	190	5·1
33	1	0·045	0·00385	53	Al	0·018	0·025	0·047	1·32	18·2	0·218	0·218	0·00200	0·037	27	435	47·3	95	2·6

TABLE II

GRADIENTS AND CRITICAL REYNOLDS NUMBER AND VELOCITIES OBTAINED FROM NON-DIMENSIONAL PRESSURE LOSS CHARACTERISTICS

Matrix No.	*Gradient*	*Critical Re*	*Critical velocity in passage* ft./sec.
1	−0·90	1800	85
2	−0·94	1700	75
3	−0·90	1900	75
4	−0·79	1900	70
5	−0·90	*	
6	−0·90	*	
7	−0·48	†	
8	−0·57	2000	75
10	−0·64	3000	110
11	−0·59	3000	110
12	−0·75	1300	65
13	−0·77	2000	100
14	−0·68	1800	90
15	−0·67	2500	120
17	−0·88	1600	90
18	−0·88	2000	110
19	−0·78	2000	110
20	−0·74	†	
21	−0·80	†	
22	−0·61	*	
23	−0·77	1800	75
24	−0·58	2700	115
25	−0·21	†	
27	−0·62	1600	90
28	−0·72	2000	110
29	−0·68	2000	110
30	−0·71	2000	110
31	−0·83	2000	120
32	−0·90	1800	110
33	−0·91	2000	120

*Experimental range of *Re* below critical.
†Critical *Re* not clearly defined.

and estimated critical Reynolds numbers are shown in Table II.

The range of critical Reynolds number was wide (from 1,300 to 3,000) and there appeared to be no correlation with geometrical parameters such as passage length, length/diameter ratio and hydraulic diameter.

The range of Reynolds number in the matrices was from 300 to 6,000. In general, laminar flow conditions in smooth channels prevail up to a Reynolds number of about 2,000 and at a rather higher Reynolds number (perhaps 3,000) the flow becomes fully turbulent. In the case of the test matrices, although the calculated Reynolds numbers were low, and frequently below 2,000, the Reynolds number for the air flow in the main duct was high, for example, with a mean velocity of 100 ft./sec. the Reynolds number was 273,000. The velocity to give laminar flow would have to be less than 0·73 ft./sec.: all pressure loss measurements would therefore be taken with fully developed turbulent flow in the main duct. The turbulent flow pattern would persist in the passages, tending towards laminar flow at the downstream end when the Reynolds number was below 2,000. For this reason it is suggested that any pressure loss correlation should be in a form similar to the relations developed for turbulent flow, rather than for laminar flow.

A correlation in the form

$$\frac{\Delta p}{\rho V^2} = (A_1 Re^{-n} + A_2)\frac{l}{d_e} + A_3$$

is suggested. n will lie in the range $0{\cdot}2 < n < 1$ since $n = 0{\cdot}2$ corresponds to fully developed turbulent flow and $n = 1$ corresponds to laminar or viscous flow. The results shown in Table II suggest a value of n in the region of 0·8. A_1 and A_2 are constants and A_3 represents the inlet and exit loss. The loss of head due to an obstruction is well known and, assuming a coefficient of contraction of 0·66, the inlet loss is

$$\left[\frac{1}{0{\cdot}66\,(1-B)} - 1\right]^2 \frac{\rho V^2}{2}(1-B)^2$$

or, approximately $(0{\cdot}5 + B)^2 \dfrac{\rho V^2}{2}$.

The exit loss (due to a sudden enlargement) is

$$= [1-(1-B)]^2 \frac{\rho V^2}{2}$$

Thus $A_3 = \dfrac{(0{\cdot}5+B)^2 + B^2}{2}$

Values of $(\Delta p/\rho V^2 - A_3)\, d_e/l$ were computed and values of A_1, A_2 and n obtained which gave the best agreement with experimental data for Reynolds numbers below the critical, resulting in the correlating equation: —

For $300 < Re \leqslant 2{,}000$

$$\frac{\Delta p}{\rho V^2} = (16{\cdot}0\, Re^{-0{\cdot}9} \pm \sigma_1)\frac{l}{d_e} + \frac{(0{\cdot}5+B)^2 + B^2}{2}$$

where σ_1 (standard deviation of the experimental values) $= 0{\cdot}0097$ and, for $2{,}000 \leqslant Re < 6{,}000$ a similar procedure gave

$$\frac{\Delta p}{\rho V^2} = (1{\cdot}413\, Re^{-0{\cdot}58} \pm \sigma_2)\frac{l}{d_e} + \frac{(0{\cdot}5+B)^2 + B^2}{2}$$

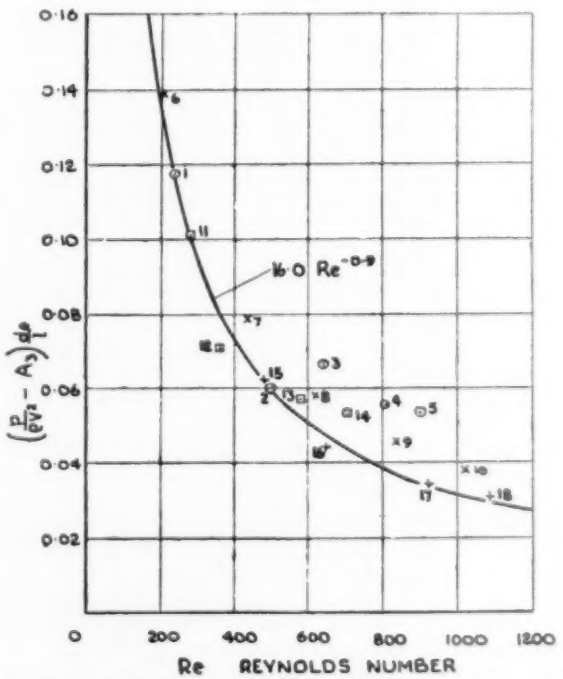


FIGURE 7. Non-dimensional resistance parameter as a function of passage Reynolds number, showing data obtained for matrix No. 9 at sub-atmospheric pressures. The numbering refers to the experimental runs listed in Table III.

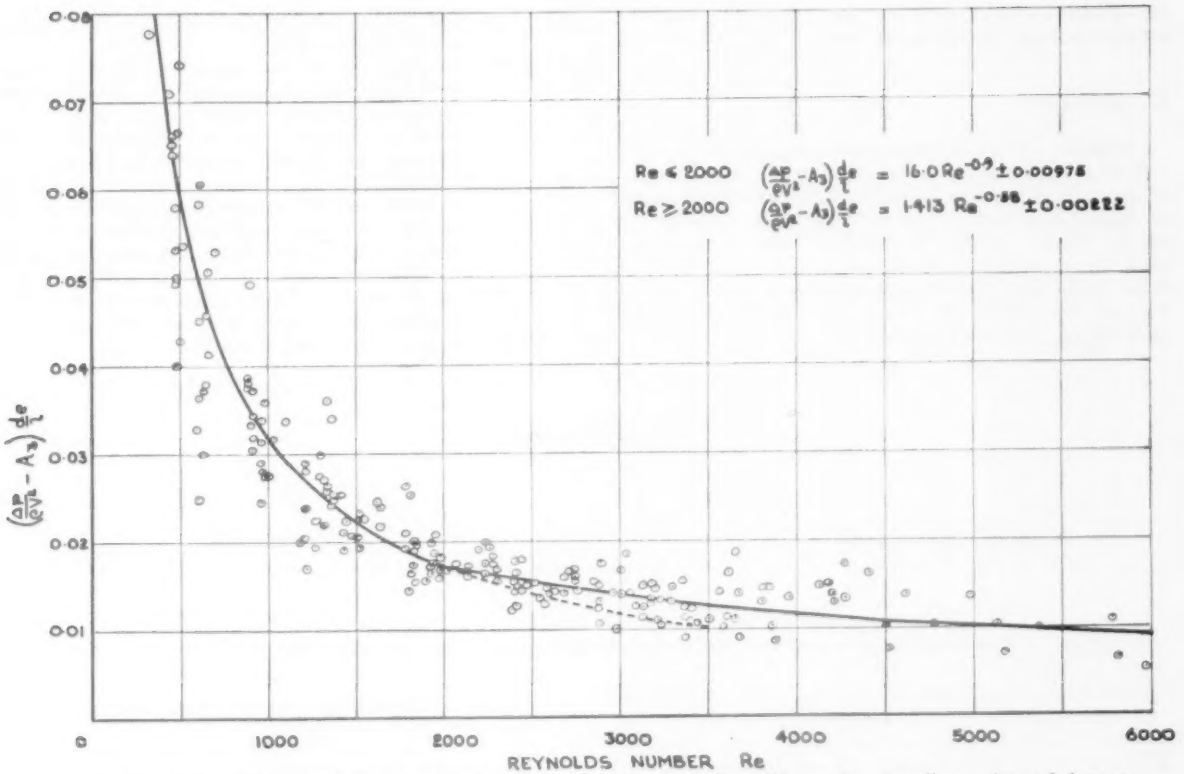


FIGURE 6. Non-dimensional resistance parameter as a function of passage Reynolds number, for all experimental data at atmospheric pressure, showing correlating equations.

where σ_2 (standard deviation of the experimental values) $= 0{\cdot}0022$. Fig. 6 shows all the experimental points, computed as $(\Delta p/\rho V^2 - A_3)\,d_e/l$, as a function of Reynolds number.

3. DATA AT SUB-ATMOSPHERIC PRESSURES

Using the correlation derived in Section 2, pressure loss data obtained for No. 9 matrix at sub-atmospheric pressures were operated on in the same way as for the atmospheric pressure data. The results are summarised in Table III.

Figure 7 shows the experimental data plotted as $(\Delta p/\rho V_2 - A_3)\,d_e/l$ as a function of Reynolds number;

TABLE III

PRESSURE LOSS DATA FOR MATRIX NO. 9 AT SUB-ATMOSPHERIC PRESSURES

Run	*Pressure loss, in. of water*	*Superficial velocity* ft./sec.	*Mean air density* lb./ft.^{3}	$\left(\frac{\Delta p}{\rho V^2} - A_3\right)\frac{d_e}{l}$	*Re*	$16\ Re^{-0{\cdot}9}$	*Predicted pressure loss, in. of water*
1	2·4	87	0·0059	0·1175	245	0·1137	2·3
2	4·8	159	0·0067	0·0598	496	0·064	4·85
3	8·9	193	0·0076	0·0670	640	0·0480	6·55
4	13·0	249	0·0079	0·0557	805	0·0389	9·4
5	17·2	278	0·0086	0·0539	896	0·0352	11·7
6	0·6	21	0·0217	0·1392	210	0·1305	0·55
7	1·6	45	0·0214	0·0789	439	0·0669	1·35
8	2·4	63	0·0216	0·0588	622	0·0488	2·0
9	3·6	89	0·0208	0·0452	838	0·0377	3·05
10	4·4	105	0·0213	0·0382	1018	0·0315	3·7
11	1·15	45	0·0122	0·1013	280	0·101	1·15
12	2·0	70	0·0122	0·0701	361	0·080	2·25
13	2·8	89	0·0119	0·0577	582	0·0524	2·6
14	4·7	127	0·0112	0·0539	708	0·0437	3·9
15	0·5	16	0·0668	0·0617	476	0·0625	0·5
16	0·7	22	0·0665	0·0444	650	0·0472	0·75
17	1·1	31	0·0667	0·0345	920	0·0346	1·1
18	1·4	37	0·0663	0·0304	1090	0·0295	1·45

the results are seen to be in good agreement with the correlating equation except for data at high velocity.

4. DISCUSSION

Although the suggested correlating equations do allow a fairly good prediction of the pressure loss characteristics of this type of matrix, the standard deviations correspond to larger differences than the estimated experimental errors. Hence, it may be concluded that factors other than those appearing in the correlating equations also affect the pressure loss through the matrices. The following are considered to be factors which reduce the accuracy of a general equation:—

(*i*) instability of flow patterns with Reynolds numbers in the critical region,
(*ii*) non-similarity of the velocity distribution within individual passages, reducing the validity of the equivalent hydraulic diameter conception,
(*iii*) effect of geometry on the persistence of the turbulent flow pattern in air entering the passages,
(*iv*) thickening of the boundary layer, the dimension of which will be appreciable compared with the passage dimension, in different lengths of passage,
(*v*) variation, with inlet velocity and geometry, of the coefficient of contraction at entry to the passages.

All these effects will be small compared with the effect of such parameters as the length/diameter ratio, but explain the inadequacy of any general equation.

The Inertial Effects of Springs in Oscillation Experiments to Determine Damping

by

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THE CALCULATION of damping from the results of resonance and free oscillation experiments has hitherto[1] been based on elementary theory in which the springs or other elastic supports are represented by lumped stiffness parameters. This "light spring theory" is generalised here to include the elastic stiffness terms in distributed parameter form; *i.e.* the mass of the springs or other supports is taken account of by including wave equations for the propagation of stress waves in the springs and so on. A record of the free motion of a model in a wind tunnel, shown in Fig. 1., indicates the inertial effects of the spring supports. To minimise this "surging" of the supports one may design them to have high natural frequencies compared with the system frequencies. However, this gives no indication of the error entailed in using light spring theory, nor does it cover experiments which must be performed at high frequencies. The analysis outlined here includes the support dynamics in the study of one typical system (Fig. 2) for determining damping. The expressions for the damping so derived for two types of oscillation experiments include inertial terms for the supports, and are shown to be reducible to a simple form for many applications. Experimental results which demonstrate the use of the theory are also given.

ANALYSIS

It will be assumed that the one-dimensional wave equation may be used to describe the motion of the elastic supports. For the extension or torsion of a bar this assumption is valid, but for a helical spring the type of disturbance decides the validity of the equation. Yoshimura and Murata[2] have shown that in the motion of a spring there are in general at least three coupled waves with velocities dependent on wavelengths. But, for wavelengths of at least the same order as the spring diameter, the motion was shown to be closely described by the wave equation. This condition appears to be satisfied in aerodynamic damping experiments.

It is also assumed that the damping is proportional to the velocity of the mass in the system to be considered.

Resonance Method

Referring to Fig. 2 the equations of motion of the system are

$$\left.\begin{aligned} \frac{\partial^2 u_1}{\partial x_1^2} &= \frac{1}{c_1^2}\frac{\partial^2 u_1}{\partial t^2} \\ \frac{\partial^2 u_2}{\partial x_2^2} &= \frac{1}{c_2^2}\frac{\partial^2 u_2}{\partial t^2} \\ M\frac{d^2y}{dt^2}+b\frac{dy}{dt} &= -k_1 l_1\left(\frac{\partial u_1}{\partial x_1}\right)_{l_1,\,t}+k_2 l_2\left(\frac{\partial u_2}{\partial x_2}\right)_{l_2,\,t}-Qy \end{aligned}\right\} \quad (1)$$

where $x_{1,2}$ position of an element of the spring referred to its unstretched axis.
$u_{1,2}$ displacement of an element of a spring from its equilibrium position.
$c_{1,2}$ velocity of a stress wave referred to the unstretched axis of the spring.
$l_{1,2}$ unstretched length of a spring.
Q a term representing any stiffness additional to the supports, *e.g.* aerodynamic stiffness.

Considering only the steady state solutions to these equations, the boundary conditions come from the ends of the supports.

Thus for example at $x_2=0$, $u_2=R\sin\omega t$ for all t.

The general solutions to the equations are

$$u_{1,2}=\sum_{i=1}^{4} A_{1,2_i}\begin{matrix}\sin\dfrac{\omega x_{1,2}}{c_{1,2}}\sin\omega t\\ \cos\dfrac{\omega x_{1,2}}{c_{1,2}}\cos\omega t\end{matrix}$$

$$y=B_1\sin\omega t+B_2\cos\omega t.$$

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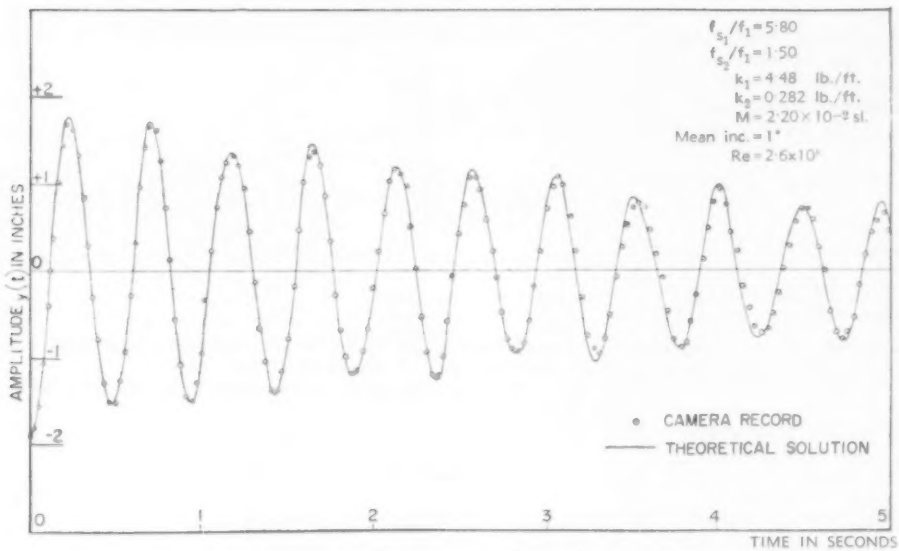

FIGURE 1. Sample camera record and corresponding solution from equation (9).

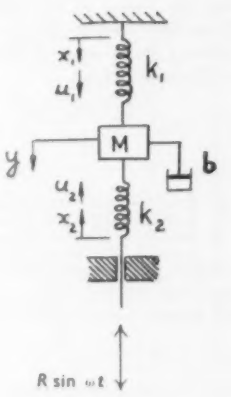

FIGURE 2.

where the $A_{1,2}$, B_1 and B_2 are ten constants.

Application of the boundary conditions produces the result

$$y = y_0 \sin(\omega t - \varepsilon)$$

where ε is the phase angle

and
$$y_0 = \frac{\gamma}{(\alpha^2 + b^2)^{\frac{1}{2}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\left.\begin{aligned} \alpha &= M\omega - \frac{k_1 l_1}{c_1}\cot\frac{\omega l_1}{c_1} - \frac{k_2 l_2}{c_2}\cot\frac{\omega l_2}{c_2} - \frac{Q}{\omega} \\ \gamma &= \frac{k_2 l_2}{c_2}\,\frac{R}{\sin(\omega l_2/c_2)} \end{aligned}\right\} \quad (3)$$

At resonance ($y_0 = y_{0r}$), $\dfrac{dy_0}{d\omega} = 0$ and

$$\frac{\gamma_r^2 Y_r}{y_{0r}^2 \omega_r} = \alpha_r\left(\frac{d\alpha}{d\omega}\right)_r + b_r\left(\frac{db}{d\omega}\right)_r \quad . \quad . \quad . \quad (4)$$

where
$$Y = \frac{\omega l_2}{c_2}\cot\frac{\omega l_2}{c_2}.$$

The subscript r denotes resonant conditions.

Since α_r is a small quantity obtained from the difference of large quantities it is desirable to eliminate it from the expressions for b_r. Substituting for α_r from equation (4) into equation (2) at resonance produces the damping b_r in the form

$$b_r^2 = \left(\frac{\gamma_r}{y_{0r}}\right)^2 - \frac{1}{\left(\dfrac{d\alpha}{d\omega}\right)_r^2}\left[\frac{\gamma_r^2 Y_r}{y_{0r}^2 \omega_r} - b_r\left(\frac{db}{d\omega}\right)_r\right]^2 \quad (5)$$

In contrast to α_r, the quantity $\left(\dfrac{d\alpha}{d\omega}\right)_r$ now has all terms positive, assuming Q is positive. If no information is available regarding the size of $\left(\dfrac{db}{d\omega}\right)_r$, recourse must be made to a method of successive approximations to obtain b_r. However for many applications, particularly in aerodynamics, it may be shown that the second term on the right side of equation (5) is negligible and the damping becomes

$$b_r = \frac{k_2 R}{\omega_r y_{0r}}\left(\frac{\pi f_r}{f_{s_2}}\right)\Big/\sin\left(\frac{\pi f_r}{f_{s_2}}\right) \quad . \quad . \quad . \quad (6)$$

where f_{s_2} is the natural frequency of the spring number 2 with both ends fixed, *i.e.* $f_s = \dfrac{c}{2l} = \dfrac{1}{2}\sqrt{\left(\dfrac{m}{k}\right)}$

and m = total mass of the spring less the end coils.

Equation (6) reduces to the "light spring theory" result

$$b_r = \frac{k_2 R}{\omega_r y_{0r}} \qquad \text{when } f_{s_2} \longrightarrow \infty$$

A graph of the inertia or surge correction factor $\left(\dfrac{\pi f_r}{f_{s_2}}\right)\Big/\sin\left(\dfrac{\pi f_r}{f_{s_2}}\right)$ is shown in Fig. 3.

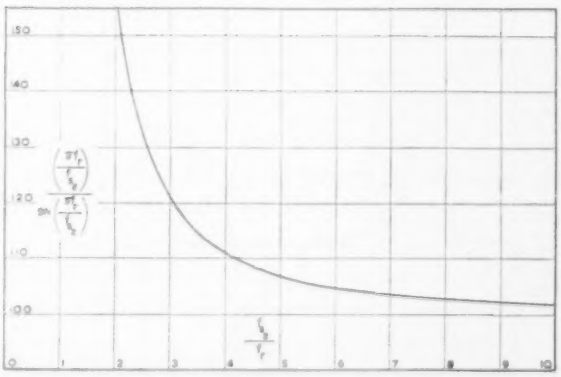

FIGURE 3. Spring inertia factor in the damping coefficient b for resonance experiments.

Free Oscillation Method

The equations of motion are as before, namely equations (1), but the boundary conditions are modified to account for the fixing of the end of the spring number 2 remote from the model. Using the Laplace Transformation and solving gives $y(t)$ in terms of y_0, the initial displacement of the mass M, as

$$\frac{y(t)}{y_0}=1-\frac{(k_1+k_2+Q)}{2\pi j}\times$$

$$\times\int_{\phi-j\infty}^{\phi+j\infty}\frac{e^{pt}dp}{p\left(Mp^3+bp+\frac{k_1p}{2f_{s_1}}\coth\frac{p}{2f_{s_1}}+\frac{k_2p}{2f_{s_2}}\coth\frac{p}{2f_{s_2}}+Q\right)} \quad (7)$$

where ϕ is chosen so that the path of the integration encloses all the poles of the integrand. These poles are all simple and are given by

$$p=0,\ \alpha_n\pm j\omega_n \qquad n=1,2\ldots\ldots\infty$$

the $(\alpha_n\pm j\omega_n)$ being the roots of

$$Mp^2+bp+\frac{pk_1}{2f_{s_1}}\coth\frac{p}{2f_{s_1}}+\frac{pk_2}{2f_{s_2}}\coth\frac{p}{2f_{s_2}}+Q=0. \quad (8)$$

The solution (7) may be reduced to the form

$$y(t)=-2(k_1+k_2+Q)\,y_0\,\mathscr{R}\times$$

$$\times\left[\sum_{n=1}^{\infty}\frac{e^{p_nt}}{\left(Mp_n^2-\frac{k_1p_n^2}{2f_{s_1}}\coth\frac{p_n}{2f_{s_1}}-\frac{k_2p_n^2}{2f_{s_2}}\coth\frac{p_n}{2f_{s_2}}-Q\right)}\right] \quad (9)$$

where $\mathscr{R}$ denotes "real part," but equation (9) does not yield an expression for b. To obtain the desired expression for b, use is made of the characteristic equation (8) which is satisfied by each root $p_n=\alpha_n\pm j\omega_n$. Experimental results in general show that the fundamental frequency f_1 predominates. Hence, if it is assumed that the mean line through the scatter of points on a logarithmic amplitude against time curve, applies to the fundamental, the damping α_1 of the fundamental is given by

$$\alpha_1=-\frac{\log_e 2}{T_{1/2}} \quad (10)$$

where $T_{1/2}$=time to half amplitude measured from the mean line.

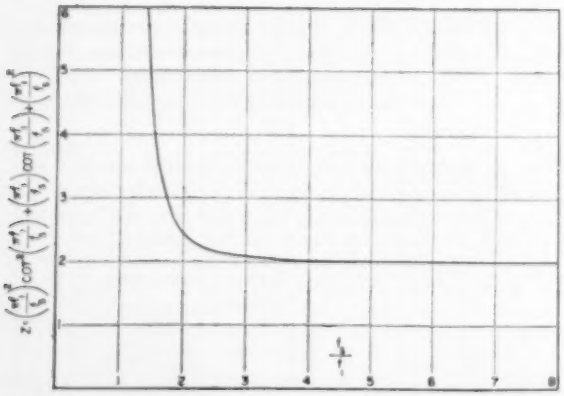

FIGURE 4. Spring inertia factor Z in the damping coefficient b for free oscillation experiments.

If equation (8) is expanded into real and imaginary parts and the resulting equations solved for b, the result is

$$b=\sum_{i=1,2}\frac{k_i}{2f_{s_i}}\times$$

$$\times\left\{\frac{\cot\left(\frac{\omega_n}{2f_{s_i}}\right)\left[1-\coth^2\left(\frac{\alpha_n}{2f_{s_i}}\right)\right]-\coth\left(\frac{\alpha_n}{2f_{s_i}}\right)\left[1+\cot^2\left(\frac{\omega_n}{2f_{s_i}}\right)\right]}{\coth^2\left(\frac{\alpha_n}{2f_{s_i}}\right)+\cot^2\left(\frac{\omega_n}{2f_{s_i}}\right)}\right\} \quad (11)$$

Equation (11) applies to all frequency components and therefore also to the fundamental.

For light damping, as in many wind tunnel experiments,

$$\left.\begin{aligned}&\coth\left(\frac{\alpha_1}{2f_{s_i}}\right)\simeq\frac{2f_{s_i}}{\alpha_1}\\ \text{and}\quad&\left(\frac{2f_{s_i}}{\alpha_1}\right)>>\cot^2\left(\frac{\omega_1}{2f_{s_i}}\right)\end{aligned}\right\} \quad (12)$$

Using these approximations and equation (10) in equation (11) gives

$$b=\frac{\log_e 2}{\omega_1^2T_{1/2}}\left[k_1Z_1+k_2Z_2+2Q\right] \quad (13)$$

the required expression,

where $Z_i=\left(\frac{\pi f_1}{f_{s_i}}\right)^2\cot^2\left(\frac{\pi f_1}{f_{s_i}}\right)+\left(\frac{\pi f_1}{f_{s_i}}\right)\cot\left(\frac{\pi f_1}{f_{s_i}}\right)+\left(\frac{\pi f_1}{f_{s_i}}\right)^2$.

A curve showing Z against f_s/f_1 is given in Fig. 4. Equation (13) reduces to the light spring theory result

$$b=\frac{2M\log_e 2}{T_{1/2}}\quad\text{for } f_{s_i}\longrightarrow\infty \text{ and light damping.}$$

It may be noted that the mass M may be obtained from a free oscillation without damping, from the expression

$$M=\frac{1}{\omega_1^2}\sum_{i=1,2}\left[k_i\left(\frac{\pi f_1}{f_{s_i}}\right)\cot\left(\frac{\pi f_1}{f_{s_i}}\right)\right] \quad (14)$$

This latter expression being particularly useful in rotary experiments where inertias may be required.

APPLICATION OF THE ANALYSIS TO AN EXPERIMENT FOR DETERMINING THE AERODYNAMIC STABILITY DERIVATIVE m_q'*

To demonstrate the foregoing analysis, a number of experiments were performed to determine the damping derivative m_q' for a model in a wind tunnel. The model was a 1/6th scale version of the E.P.B.I.A. tail-less glider, without end plates or canopy. For small angles of rotation in pitch, the system was equivalent to Fig. 2, and the model moment of inertia in pitch B was related to the mass M in Fig. 2 by

$$M=\frac{B}{d^2}.$$

Also,
$$b=-\frac{M_q'+\mu}{d^2}$$

*$m_q'=m_q+m_{\dot{w}}'=\rho V^2Sl_TM_q'$ in the usual notation.

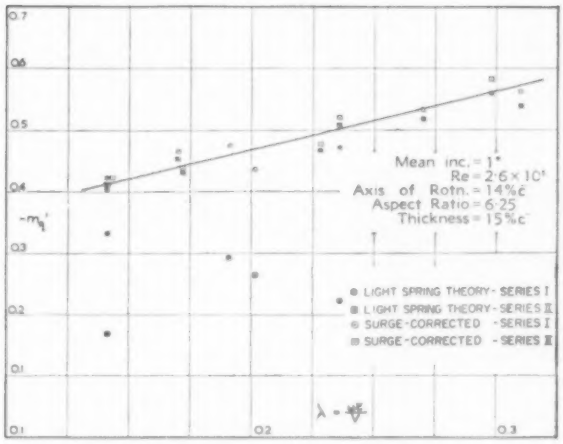
Mean inc. = 1°
Re = 2·6 × 10⁵
Axis of Rotn. = 14%c
Aspect Ratio = 6·25
Thickness = 15%c
LIGHT SPRING THEORY - SERIES I
LIGHT SPRING THEORY - SERIES II
SURGE-CORRECTED - SERIES I
SURGE-CORRECTED - SERIES II

FIGURE 5. Results of resonance experiments.

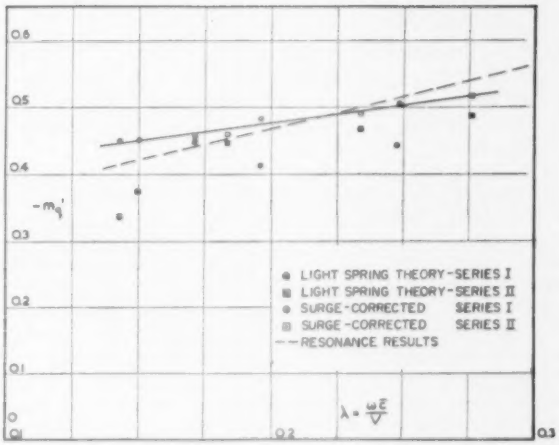

FIGURE 6. Results of free oscillation experiments.

where d=tail sting length between model axis of rotation and the springs

and μ=apparatus damping coefficient.

Also, the stiffness term Q becomes $Q=\dfrac{-\rho V^2 S\bar{c}}{2d^2}\dfrac{dC_m}{d\theta}$

A Ward-Leonard speed control system was used for the d.c. driving motor in the resonance experiments. Amplitude measurement was by pointer and scale, a camera being used for the free oscillations.

Properties of the Two Series of Springs and Scope of Tests

Two series of springs were used. In series I the springs had low natural frequencies, while those in series II had high natural frequencies compared with the forcing frequencies. A minimum weight spring design by Spotts[3] was partly used in series II.

The derivative m_q' was determined as a function of the non-dimensional frequency parameter $\lambda=\dfrac{\omega\bar{c}}{V}$ for

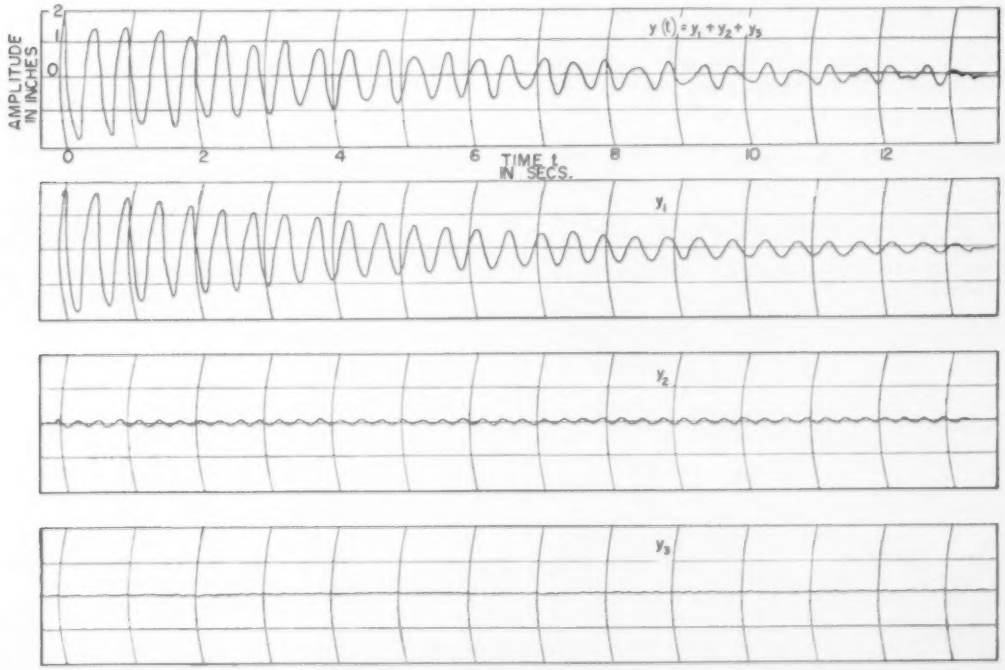

FIGURE 7. Extended record of the theoretical solution in Fig. 1, with the first three frequency components (y_1, y_2, y_3) to scale.

constant Reynolds number and mean incidence. Changes in λ were produced by changing spring stiffness or model inertia at constant wind speed.

Experimental Results

The values of m_a' calculated on the basis of light spring theory are compared in Figs. 5 and 6 with the surge-corrected results of experiments performed by both methods using springs of both series. The dotted line in Fig. 6 shows the mean line through the resonance results. The most noticeable effect of spring surging in the experiments was the "beating" between the first few predominating frequencies in the free oscillation records. The beating was readily observed for results of both series when the peak amplitudes were plotted logarithmically against time and a waviness appeared in the distribution of points*. A theoretical solution determined from equation (9) is shown in Fig. 1 compared with the corresponding experimental points. The reduced damping of the higher frequency components is shown in Fig. 7.

Discussion

The effects of spring surging are evident in Figs. 5 and 6 where the small scatter of the corrected results was within the experimental error. The different slopes of the mean lines through the results of both methods were apparently due to amplitude effects[4]. The tendency of a spring to resonate as its natural frequency is approached gives the spring a lower effective dynamic stiffness and hence an increased amplitude of any attached load. In a damping experiment, therefore, light spring theory will give a low estimate of the damping present in the system.

For the resonance experiments it was found that the first approximation of equation (6) gave values of b which differed by only 2 parts in 10^4, in the worst case, from the values obtained from the second approximation obtained with equation (5). Hence equation (6) may be applied to these experiments, but in other cases it may be advisable to check its validity with the help of equation (5).

In contrast to the surge correction factor $\left(\frac{\pi f_r}{f_a}\right) \Big/ \sin\left(\frac{\pi f_r}{f_a}\right)$ in the resonance method, the factors $Z_{1,2}$ provide only a portion of the correction to free oscillation results. Most of the surge correction in the latter case, comes from the fact that $\frac{k_1+k_2}{\omega_1^2} > M$ for massive springs where ω_1 is the fundamental frequency with damping present (*see* equation (14) where ω_1 is the fundamental frequency *without* damping).

In the worst case encountered in the free oscillation experiments, the error involved in using the approximations (12) was less than 0·1 per cent.

A more detailed account of this work is to be published[4].

*A search of the literature revealed such waviness in all the examined semi-logarithmic plots of the amplitude decay in free oscillation experiments to determine stability derivatives. This is an indication that the results of all such experiments are likely to be a few per cent in error due to neglect of the effects of spring inertia.

CONCLUDING REMARKS

The analyses given enable the effects of spring mass on damping experiments to be calculated. For both resonance and free oscillation experiments the quantity of importance is shown to be the ratio $f_a/f_{r,1}$. To minimise inertia effects, the values of this ratio should be as high as possible. But even for the highest practicable values, errors of the order of a few per cent occur in the damping coefficient, if the inertia effects are neglected. This error increases with the frequency of the oscillations.

Only one typical system has been considered in the present note but the analyses are applicable to other systems where the motion of the constraints is governed by the wave equation.

ACKNOWLEDGMENTS

The author acknowledges the advice and assistance of Mr. P. T. Fink of the Department of Aeronautics, University of Sydney. Thanks are also due to Professor W. H. Wittrick of the same Department and to Mr. R. E. Center for his help with the experiments. The author is indebted to the Chief Scientist of the Australian Department of Supply for permission to publish this note.

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Graduates' and Students' Section

Courtesy of de Havilland Aircraft Co. Ltd.

The revised version of the Airco D.H.121 ordered by B.E.A. as a Viscount replacement.

Annual Dance

The date for this year's dance is Friday 20th November, so now is the time to note it in your diary. Further details will be given next month.

Lecture: The Setting of Aircraft Specifications

Mr. R. H. Whitby, who will speak to us on 28th October, is the Performance and Analysis Manager of the B.E.A. Project and Development Branch. Specifications which have resulted in orders for the Vanguard, D.H.121 and the Tyne-Rotodyne have all come from this Branch in recent years, and their importance to the Aircraft Industry in this time of reduced military contracts needs no emphasis.

Mr. Whitby was in charge of Aero (Projects) at R.A.E., Farnborough, before joining B.E.A. in 1946 to work on helicopter research and development. He took up his present position in 1953 and is responsible for aircraft project analysis, flight test and provision of performance and loading data for B.E.A. aircraft.

Lecture: The Flight Testing of Rotorcraft

On Wednesday 11th November Sqn. Ldr. W. R. Gellatly will be speaking to us on his experience in the rotary wing field. He is at present Senior Rotary Wing Test Pilot of Fairey Aviation and is hard at work on Rotodyne flight trials.

Sqn. Ldr. Gellatly is no newcomer to this field. He joined the Royal New Zealand Air Force in 1940 and obtained a Permanent Commission in 1947. After the E.P.T.S. Course at Farnborough in 1950 he served as Helicopter Flight Commander at Boscombe Down until 1954. He joined his present company in 1955 and his first job was the flight testing of the Ultra Light helicopter, and many will remember his spectacular high speed descents with this aircraft at the Farnborough Show.

The prototype Rotodyne is shown here moving a large bridge into position. B.E.A. intend to order the developed version with Tyne engines.

Courtesy of Fairey Aviation Ltd.

THE LIBRARY

Reviews

FIRE CONTROL PRINCIPLES. *Walter Wrigley and John Hovorka. McGraw-Hill, New York, 1959. 133 pp. Illustrated. 77s. 6d.*

The great merit in this book lies in the fact that it is the first published work which attempts to lay down general design principles applicable to all fire control systems whether they be sea, land or airborne. Like a number of American texts, it is based upon a course of lectures—this particular course being at graduate level at Massachusetts Institute of Technology for selected officers of the American Armed Forces.

The book should be of direct value to all engineers and serving officers who are concerned with the development and assessment (particularly comparative assessment) of conventional armament fire control systems, *i.e.* guns, rockets and bombs. To those who are interested in guided weapon fire control systems, the book will prove something of a disappointment (in spite of the claim of the authors) although indirectly it still has value.

The reason for this is the authors' definition of fire control principles. They state in Chapter I that the common factor in all fire control systems is the prediction of the angle of launch of an unguided projectile from its "weapon station." The solution of this problem is then made the subject of the book. Navigation of the "weapon station" to its firing position is dealt with only insofar as it affects the accuracy and the design of prediction computers, and thus appears in the chapter entitled "Fire Control Computing Systems." It is understandable, therefore, that the authors are in difficulty when trying to fit surface-to-air and air-to-air guided weapons into the pattern of the book, for the whole purpose of these weapons is to eliminate the prediction problem, reducing the problem to one of navigation only. Incongruously, they are discussed under a chapter entitled "General Features Common to All Fire Control Systems," when it would have appeared more appropriate (if they were to be discussed at all) to have considered them alongside the analogous problem of navigation of the "weapon station."

One would have thought that in attempting to write a general thesis on fire control principles the authors would have sought, not only common factors, but also the lowest common denominator of these factors. This would then form a general pattern into which all fire control systems would fit. Certainly, the navigation problem of the "weapon station" should be included, since, in many systems, this and the prediction problem are inextricably inter-related.

The fire control problem as stated is analysed very efficiently. Chapter 2 which formulates mathematically the fire control problem is particularly good. Vector methods are used since this provides the simplest solution, and the "definition summaries" of the preceding chapter should serve to convince readers that vector techniques are not difficult. An additional "definition summary" proving the Coriolis relationship for accelerations would have added completeness.

Chapter 3 very efficiently classifies fire control systems according to computing techniques. Chapter 4 gives a very readable survey of various gyroscopic arrangements, many of which are used in the guided weapon field. Chapter 5 deals very broadly with fire control computer systems. This could be amplified with advantage. Chapter 6 summarises the conclusions of the preceeding chapters.

The book is lavishly illustrated and is remarkably free from misprints. There are a few minor criticisms such as phraseology and American terminology which at times proves troublesome, a suffix system which might be simplified, and diagrams and summaries which on occasion were well-divorced from the text. In spite of its limitations, the book makes a valuable contribution in rationalising the subject, and leads one to hope that a later edition might be forthcoming, generalising the subject still further so as to include all fire control systems including guided weapons. In this way, ideas and experience of the past and present can be marshalled to improve the systems of the future.—E. J. HOLDEN.

HYPERSTATIC STRUCTURES. *J. A. L. Matheson. Butterworths, London, 1959. 474 pp. Illustrated. 90s.*

One must admit that the various branches of engineering do tend to become parochial. For this reason aircraft structural engineers may sometimes feel with guilt that they have an over-possessive attitude towards the analysis of redundant structures. It is therefore with inevitable feelings of bias, but with particular interest, that one looks at a newly-published work on the subject.

The publishers' "blurb" on the dust cover of Professor Matheson's book says that "it treats the subject of hyperstatic structures as an organic and coherent whole." The author himself, in his preface, modestly contents himself with stating this to be merely his aim. It is exciting to pick up a work which has such an aim, for in so many cases the subject is treated as a set of separate problems with separate detailed solutions. It must be remembered, though, that the field is not empty; and any book of this character must be able to stand beside such as Hoff's *The Analysis of Structures*.

It would be fair to say that Professor Matheson amply succeeds in his aim in the first hundred or so pages of his book. In these he covers definitions and basic methods, and examines the various structural theorems and their relationships.

So far so good; but in Chapter 3, which is entitled "General Theorems for Linear Elastic Structures" there intrude details of the calculation of deflections in pin-jointed frameworks and in beams. Thereafter it is detail, detail all the way. Chapter 4, on "General Methods for Linear Hyperstatic Structures" is illustrated with framework after framework, truss after truss. Chapter 5 deals with moving loads and influence lines in an orthodox way, and Chapter 6 covers rigid-jointed frameworks. Chapter 7 comes closest to the interests of the aircraft engineer, covering arches and dealing with methods directly applicable to frame stressing. Chapter 8, by Dr. N. W. Murray, uses methods very similar to those of the R.Ae.S. Structures Data Sheet 02.01.28 to solve problems of the overall instability of framed structures. The final chapter, by Dr. R. K. Livesley, is in the nature of an appendix, covering matrix methods of analysis with an eye to digital computer techniques.

Remembering that the aircraft structural engineer is no longer almost alone in dealing with shell structures, it can hardly be regarded as a parochial criticism to complain that this "logical and coherent" treatment ignores com-

pletely such an important class of hyperstatic structures. One feels that the book under review is not one but two: the beginnings of an excellent general review of the title problem to which has been added an "engineer's text-book" on the details of the analysis of a limited class of that problem. On comparing it with Hoff's book one feels that it gives nothing like the sense of co-ordination and unity that that excellent volume does.

The presentation is excellent, marred only by an occasional solecism. Two such are the dreadfully set equation before 3.3 on p. 91, and the example on the portal frame on p. 362. This poor frame is loaded by a single force, curiously labelled $3\frac{1}{2}P$, its linear dimensions are given in feet, its flexural rigidities are non-dimensional, and its bending moments are in units of P. Oh Lanchester! Oh LMT!—K. H. GRIFFIN.

APPLIED HYDRODYNAMICS. *H. R. Vallentine. Butterworths, London, 1959. 272 pp. Diagrams. 50s.*

This book is "intended for use in Universities as an introduction to Hydrodynamics for students of Applied Mathematics, and as a course in Fluid Dynamics for senior and post-graduate students in Civil, Mechanical and Aeronautical Engineering." The subject is developed from its fundamental principles and, although some of the text is highly mathematical, it is explained in a manner which should enable engineers to penetrate the mysteries of hydrodynamics—and especially those of conformal transformations (which occupy over a third of the book). Most of the book is concerned with the mathematical theory of two-dimensional flow of a perfect fluid. In the last chapter, three-dimensional irrotational flow is considered, attention being mainly restricted to axisymmetric flows. Thus, as its title implies, this book will be of more use to hydrodynamicists than to aerodynamicists.

The order of presentation of the subject differs from the usual order, the aim being to "forewarn the students regarding possible sources of error in the application of the methods" to be developed subsequently. While this is a very laudable aim, it has its drawbacks. Thus, on page 3, in a chapter entitled "Flow of an Ideal Fluid," the student is confronted with a digression on properties of viscous fluids which could, with profit, be reserved for Chapter 2 (on "Flow of a Real Fluid"). In the first chapter streamlines, stream functions and velocity potential functions are all defined, but one reader would have preferred far more examples (and practical ones) to be given here. A large number of examples is given in Chapters 3 to 6, but more are needed at an early stage to ram home the author's thesis that these are not merely mathematical abstractions but exceedingly useful quantities. Velocity potential is defined (in the first chapter) without reference to circulation; this will not help the non-mathematical student.

In Chapter 2 we get into deep water with the Navier-Stokes equations for three-dimensional flow (given without adequate proof). It would have been better if the author had concentrated on simple one- and two-dimensional flows, and had given a proof of the formulae for the drag of a flat plate (and for the variation of the boundary layer thickness). The treatment of laminar and turbulent flow is not satisfactory; the impression is given that pressure is constant across the boundary layer for turbulent flows only.

A very clear exposition is given of numerical methods of flow analysis, including the application of relaxation techniques to simple flow patterns. There are problems at the end of every chapter and answers are given.

This book will probably be useful as a "second" book for a student to read on this subject, especially if he is interested in conformal transformations.—A. W. BABISTER.

INTRODUCTION TO MONOPULSE. *Donald R. Rhodes. McGraw-Hill, London, 1959. 119 pp. Illustrated. 46s. 6d.*

This book is based on a mathematical analysis of what the author calls his "three basic postulates" which he refers to as an "abstract idealism." He claims that it seems to define the theoretical limits of practical monopulse systems. The transformation from angle of arrival to an unbalance in a signal ratio and the detection of this as an error signal are treated as two mapping transforms of a complex variable from one complex plane to another.

The introduction, as does the remainder of the book, almost completely ignores any British work in the field. It is also incomplete in that the author refers only to the use of monopulse or simultaneous lobing in non-coherent pulse radar systems without referring to its use in any direction-finding system using, for instance, Continuous Wave or Frequency Modulated transmissions. After the analysis of his basic concepts there are chapters giving brief outlines of possible systems and antenna principles.

The author claims that he is more concerned with concepts than with specific systems and design data. However, even the basic concepts could be dealt with in a more practically useful way. Whichever concept is used to reduce any monopulse system to one of a small number of standard forms the importance of various practical limitations will vary from system to system. These include such points as gain and phase matching in various parts of the overall receiver chain, matching of A.G.C. characteristics in different channels, and the degree of balance obtainable in the hybrid transformers in the system. Some of these points are not mentioned at all and others are dealt with only very briefly. No attempt is made to generalise such effects and relate them to the angle sensing sensitivity of the aerial system in order to convert them to bias errors or to changes in sensitivity.

The chapter on antenna principles provides only an outline approach and many of the basic problems involved in practice, such as the matching of both sum and difference feeds and the various unusual effects which can come from the use of offset and asymmetric aerial and feed systems, are not mentioned.

The book claims to offer a general introduction to the principles of monopulse for students and practising engineers. There is no doubt that such a book would be very useful, but this one does not provide a very satisfactory introduction for anyone wanting to do actual work in the field.—J. D. CLARE.

METALS FOR SUPERSONIC AIRCRAFT AND MISSILES. *D. W. Grobecker (Editor). American Society for Metals, Cleveland, Ohio, 1958. 432 pp. Illustrated.*

Any book consisting of a compilation of technical papers generally falls short of a reader's requirements. They may provide a useful reference for those who attended the original technical session, but they rarely form integrated reading matter for those who did not. It is refreshing to find that *Metals for Supersonic Aircraft and Missiles* avoids this literary pitfall and provides factual and valuable data presented in a practical sequence.

Engineering design in aeronautics is an increasingly complex business, particularly where the effect of elevated temperatures has to be considered, and "Modern Technology," says a contributor, "requires an increased partnership between materials and design engineering, and depends to an increasing extent on many specialised scientific skills."

The broad conception of stresses involved in a structure or power unit for high speed flight is well known, but what is open to doubt is the value and accuracy of data generally made available; here in the opening chapters the values and shortcomings of such data are laid open for inspection, to which the reader may apply his own experience and theories.

"The thermal thicket," as it has been called, is a most apt title for the problems which are usually tackled either in a manner more fitting to science fiction or to complex mathematical treatment (which leaves the designers even more bewildered!). This book fortunately does neither: the practical engineer and designer will appreciate the manner in which the problem and the causes are set down. Wisely it does not attempt to give conclusive answers to those, but indicates the lines on which they may be tackled, and the probability results.

To appreciate fully the chapter on kinetics and oxidation, the reader should be a chemist or physicist, but the engineer can make practical use of this chapter as the different effects of oxidation of various materials are discussed at length, with tabulated data of theoretical and observed weight loss under different conditions.

From this aspect it seems natural to proceed to the following chapter on protective coatings, and here, not only are the more common substances such as nickel, chromium, aluminium, and so on, discussed, but also metals such as rhenium, platinum, borides and carbides of titanium, zirconium, hafnium etc. Methods of application, stability, hardness and other characteristics are fully dealt with in relation to temperature. Diffusion bonds and multi-layer plating is also well presented.

The following chapters of this volume are devoted to various specific materials, and the effect of temperature on their properties and characteristics. Conveniently divided into sections dealing with (*a*) light metals such as aluminium, magnesium and titanium, (*b*) stainless steels, (*c*) heat resistant alloys of nickel and cobalt, and finally (*d*) properties of the less common metals, such as chromium, iridium, molybdenum, and so on, there is little new to be read from these chapters, but they clearly set down all the data relevant to their application in areas subjected to elevated temperatures.

The last two chapters deal with metal ceramic combinations and the properties of specific ceramics and cermets.

To the individual with design responsibility, the value of having a wide range of authentic information is inestimable. Clearly and factually stated, no difficulty is experienced in finding information relating to a particular aspect and wisely the book does not try to ram theories down the reader's throat, but rather tries to present the problems, to examine each aspect in turn, and then leave the reader to form his own answers based on his own perception and impressions.—R. D. CULLUM.

MATERIALS FOR ROCKETS AND MISSILES. *Robert G. Frank and William F. Zimmerman. Macmillan, London, 1959. 124 pp. Illustrated. 31s. 6d.*

Missiles must be almost as old as man himself; for early in history the throwing of what one did not want at someone who wanted it still less was a simple and sometimes effective way of expressing emphatic disagreement. This technique has certainly stood the test of time.

As early as the 13th century, rockets were in military use in China. Later they were used in Europe but, after two or three centuries of rather limited use, they suffered virtual extinction owing to the more rapid development of the muzzle-loading gun. Their later revival in this country came about in an interesting way.

In the last quarter of the 18th century, during the campaigns against Hyder Ali and his son, Tippo Sahib, rockets were used against the British forces in Mysore. The infantry, as ever, stood their ground but the cavalry, admittedly in spite of themselves, galloped off madly in all directions. Both arms, after this experience, not having been in a position to reply in kind, complained about it. One result of this wailing in Whitehall was the stimulation of the inventive powers of one William Congreve. He was the son of the Comptroller of the Royal Laboratory at Woolwich Arsenal where fireworks were then made for adding to the doubtful gaiety of Royal garden parties.

With this background and the active interest of the then Prince of Wales (later George IV) Congreve's idea was quickly adopted. Between 1805 and 1815 his rockets were extensively used. Expert opinion as to their value was, as ever, hotly divided against itself. In retrospect it would, nevertheless, seem that these weapons had considerable moral effect but, like their successors of today, were all too often misguided or misdirected as to the whereabouts of their target. In view, however, of the country of origin of the book to which the above forms an introduction, it is no unseemly pleasantry to mention that one of the greater rocket achievements was in North America, an area where British arms have not been uniformly successful. Both British and American historians, with varying degrees of appreciation, attribute the capture and burning of the city of Washington in 1814 to Congreve's rockets.

Had the authors of the present volume decided to produce a book on the materials used for the construction of such weapons at the end of the Napoleonic wars, their task would have been light indeed. They would have had to write merely of wrought iron, copper and solder, about all of which, be it remarked, little was then in fact known. Having to deal with the same subject nearly a century and a half later, they are forced to say something of the chemical, physical and mechanical properties of nearly forty cast or wrought alloys, falling into seven groups: iron, nickel, cobalt, molybdenum, titanium, aluminium and magnesium, and with about half a dozen cermets.

Since between the air-to-air rocket and the intercontinental ballistic one, there are probably more than 57 varieties of related weapons, with operational lives varying from seconds to substantial proportions of an hour, the authors have set themselves a task impossible of detailed performance within the ambit of one small book. They cannot give a picture: they can, however, present a sketch. This they have done and it is by no means an uninteresting one, particularly if the reader is a metallurgist with an engineering background, rather than the reverse. The book has, however, been written by Americans for Americans in American. Of nearly forty alloys to which reference is made by U.S. specification or by proprietary name, not a single British equivalent is given. Of nearly thirty authoritative works to which the authors direct attention, but one tenth have originated outside the United States. In many other lands beyond the confines of this great republic, there are, however, many quotable authorities. The units in which the authors express themselves are not those normally used in this country and the same is true of some of the words they use, such as "fixturing", a treatment which might be advantageously applied in odd places in the text, where the "o" in the chemical symbol for molybdenum appears to have become detached.—P. L. TEED.

Additions to the Library

First Colloquium on the Law of Outer Space. The Hague, 1958. A. G. Haley and W. Heinrich, Prince of Hanover. (*Editors*). Springer, Vienna. 1959. 126 pp. 32s. 6d. A collection of the 27 papers and contributions read at the First Colloquium on the Law of Outer Space . (The Second Colloquium was held in London in September 1959, in conjunction with the Tenth International Astronautical Congress.) During the First Colloquium, the participants voted to establish a Permanent Legal Committee of the International Astronautical Federation and the members of the Committee are listed as an Appendix to this volume.

Flow in the Vaneless Diffuser of a Centrifugal Compressor. W. E. Thompson, Jr. Illinois Inst. of Technology. 1958. 343 pp. Illustrated. (Ph.D. Thesis.)

Friction and Wear. R. Davies (*Editor*). Elsevier (Distributed by D. van Nostrand, London). 1959. 191 pp. 36s. 6d. The Proceedings of a Symposium held at the General Motors Research Laboratories in Detroit in 1957. Eight papers were given, one of which only is by a non-American (F. P. Bowden of Cambridge). A useful addition to a literature that is not particularly well served. A refreshing sentence in the preface states "There was no prepared discussion; the informal comments of the participants constitute a major part of the achievement of the symposium."

From Euclid to Eddington. Sir Edmund Whittaker. Dover, New York (Constable, London). 1958. 212 pp. 11s. Published by arrangement with the C.U.P. this book, with the sub-title "A study of conceptions of the external world" represents the substance of the 1947 Tarner Lectures in which the author "attempted to trace the development of theories in natural philosophy from the rediscovery of Euclid by Western scholars to the present time."

Fundamentals of Radio Telemetry. Marvin Tepper. Chapman and Hall, London. 1959. 116 pp. Illustrated. 24s. *To be reviewed.*

Handbook of Geophysics for Air Force Designers. U.S. Geophysics Research Directorate. U.S. Air Force. 1957. 433 pp. No Price. A "reference only" item. Compiled at the U.S.A.F. Cambridge Research Center by an editorial staff of six and over 50 contributing authors to provide information about the anticipated natural environment of U.S.A.F. weapon systems.

Heat Bibliography 1957. Mechanical Engineering Research Laboratory Heat Division, East Kilbride, Glasgow. 1958. 377 pp. No price. This is the fourth of a series and the first to be confined to one year only. A frightening number of references.

Heat Transfer and Fluid Mechanics Institute. Preprints of Papers. Stanford University Press (O.U.P.). 1959. 243 pp. 60s. Eighteen papers divided into sections under Rarefied Gas Flows; Magnetohydrodynamics; Fluid Mechanics and Heat Transfer; Ablation, Mass Transfer and Separation; Novel Technique and Ideas. Each paper has a substantial list of references.

Matrix Approach to Flutter Analysis, A. W. P. Rodden. I.A.S. 1959. 36 pp. 1.50 dollars. No. 23 in the S.M.F. Fund FF series. The method outlined is said to offer several advantages over the assumed mode method. Twenty references are given.

Next Ten Years in Space 1959-69, The. U.S. Select Committee on Astronautics and Space Exploration. U.S.G.P.O. (H.M.S.O.). 1959. 221 pp. 5s. 5d. A collection of "informed opinion," both domestic and foreign, made as the result of "evidence of a keen desire on the part of the American public to learn what discoveries and advances may be ahead in the new space age." Should make interesting reading in 1970. English prophecy is represented by Arthur C. Clarke and by Professor Lovell.

On Mathematics and Mathematicians. R. E. Moritz. Dover, New York (Constable, London). 1958. 410 pp. 16s. A Dover edition of a book previously published in 1914 and 1942 and originally entitled Memorabilia Mathematica or The Philomaths Quotation-Book. There are 2160 quotations under 21 chapters on various aspects of mathematics and these are exhaustively indexed. A bedside book.

Philosophy and the Physicists. L. Susan Stebbing. Dover, New York (Constable, London). 1958. 295 pp. 13s. First published (1937) by Methuen.

Philosophy of Space and Time, The. Hans Reichenbach. Dover, New York (Constable, London). 1958. 295 pp. 16s. A translation of "Philosophie der Raum-Zeit-Lehre," first published in 1927.

Report from the Select Committee on Nationalised Industries (Reports and Accounts). The Air Corporations. H.M.S.O. 1959. 369 pp. 20s. The proceedings of the committee, minutes of evidence and appendices.

Story of Aircraft, The. R. J. Hoare. A. and C. Black, London. 1958. 80 pp. Illustrated. 9s. 6d. A book for children about civil aircraft and airlines of the world, touching briefly on the most important aspects of the subject. Rather spoilt by a few errors. At least one statement is misleading, namely that the Comet was withdrawn from service following an accident in 1954 and no reference to its triumphant return to service.

Symposium on Elevated Temperature Strain Gages. American Society for Testing Materials. A.S.T.M. 1958. 163 pp. $4.50. Sponsored by Aeronautical Structures Laboratory, Naval Air Material Center in December 1957, the Symposium consisted of 13 papers, and 10 panel discussions. Temperatures dealt with are in the 1000°F. range. "It is to be noted that no investigator has reported on a device to replace the resistance gage, although the shortcomings of the latter at elevated temperatures are well documented herein." It is No. 230 in their excellent S.T.P. series.

Synthetic Aviation Turbine Oil—Ten Years Experience. Esso Petroleum Co. Ltd. 1959. 28 pp. No price. Describes the development, uses, properties and so on of Esso Aviation Turbo Oil 35.

Theory of the Jet Flap in Three Dimensions, A. E. C. Maskell and D. A. Spence. Royal Society. 1959. 18 pp. Reprint of a paper (Volume 251, 1959).

Reports

AERODYNAMICS

BOUNDARY LAYER—*see also* WINGS AND AEROFOILS INTERNAL FLOW

A theory of the separated flow from the curved leading edge of a slender wing. J. H. B. Smith. R. & M. 3116. 1959.

The simple method used by Brown and Michael to represent the flow past a slender delta wing with leading edge separation, is extended to treat wings which have pointed apexes, curved leading edges and straight, unswept trailing edges. The vorticity of the fluid near the leading edge is represented by an isolation vortex of varying strength, which is curved in the non-conical cases considered here. A step-by-step method of calculation is used which starts from an assumed conical flow near the apex and employs the condition of zero total force on the vortex system in one cross-flow plane to obtain the configuration in the next. Numerical values of the co-ordinates and strength of the vortex, the lift coefficient and

the centre of pressure position are found for three plan form families at different incidences.—(1.1.4.1×1.10.1.2).

The formation of regions of separated flow on wing surfaces. Part I. Low-speed tests on a two-dimensional unswept wing with a 10 per cent thick R.A.E. 101 section. Part II. Laminar-separation bubbles and the mechanism of the leading-edge stall. L. F. Crabtree. R. & M. 3122. 1959.
Tests of a two-dimensional straight wing with a 10 per cent thick R.A.E. 101 section have been made in a low speed wind tunnel to check the validity of a criterion suggested by Owen and Klanfer for the type of bubble which will be formed when a laminar boundary layer separates from the surface of an aerofoil. A brief discussion of the physical structure of bubbles is given, and the more important problems yet to be solved are indicated. A hypothesis is put forward to explain the phenomena of the "leading edge stall" aerofoil sections, and some remarks are added on the scale effect on the maximum lift attained by aerofoils which experience this type of stall.—(1.1.4.1×1.10.2.1).

COMPRESSIBLE FLOW—*see also* INTERNAL FLOW
THERMO-AERODYNAMICS
WINGS AND AEROFOILS

Methods for estimating distributions and intensities of sonic bangs. D. G. Randall. R. & M. 3113. 1959.
Methods recently developed for estimating distributions and intensities of sonic bangs are described. They are applied to several interesting flight manoeuvres and the results discussed in detail. The effect on sonic-bang distributions and intensities of refraction (caused by the temperature gradient existing in the actual atmosphere) is also considered.—(1.2.2).

CONTROLS—*see* WINGS AND AEROFOILS

INTERNAL FLOW—*see also* THERMO-AERODYNAMICS

The estimation of shock pressure recovery and external drag of conical centre-body intakes at supersonic speeds. E. L. Goldsmith and C. F. Griggs. R. & M. 3035. 1959.—(1.5.1×1.2.3.2×27).

Experimentelle Untersuchungen an geraden und gekrümmten Diffusoren. H. Sprenger. Inst. fur Aero. Zurich. Mitt. 27. 1959. (*In German*).
Systematic experimental investigations were carried out to determine the influence of the frictional boundary layer on the incompressible flow in channels with pressure rise along the axis. Fourteen straight and curved diffuser models having 10 cm. inlet diameter were used.—(1.5.1×1.1.0.1).

LOADS—*see* WINGS AND AEROFOILS

PERFORMANCE ESTIMATION

An analysis of steady straight flight with inclined thrust. S. B. Gates and A. W. Thorpe. R. & M. 3096. 1959.
Griffith's proposal to achieve vertical take-off and landing at the usual attitude demands sea level thrust considerably greater than the weight and continuously rotatable through 90 deg. A study of the steady states of such a system is necessary as a preliminary to work on the flying techniques involved in the project. A vectorial method of analysis has proved useful in displaying the special features of the performance of such aircraft at both high and low speed.—(1.7).

Note on the minimum power required for flight at low airspeeds. R. J. Templin. N.R.C. Report L.R.-245. *May* 1959.
An idealised form of aircraft, having a lifting wing and a jet or slipstream issuing at an angle to the flight direction so as to produce lift and thrust, is considered. The power required to produce the kinetic energy of the jet is calculated for all flight speeds down to zero.—(1.7).

STABILITY AND CONTROL—*see also* WINGS AND AEROFOILS

Investigation of the stability of very flat spins and analysis of effects of applying various moments utilizing the three moment equations of motion. W. J. Klinar and W. D. Grantham. N.A.S.A. Memo 5-25-59*L. T.I.L.* 6459. *June* 1959.—(1.8.3.1).

Effect of artificial pitch damping on the longitudinal and rolling stability of aircraft with negative static margins. M. T. Moul and L. W. Brown. N.A.S.A. Memo 5-5-59*L. T.I.L.* 6463. *June* 1959.—(1.8.0.1).

THERMO-AERODYNAMICS

Source distribution method for unsteady one-dimensional flows with small mass, momentum, and heat addition and small area variation. H. Mirels. N.A.S.A. Memo 5-4-59*E. T.I.L.* 6457. *June* 1959.
The method is illustrated by several examples including the determination of perturbations in basic flows consisting of (*i*) a shock propagating through a non-uniform tube, (*ii*) a constant velocity piston driving a shock, (*iii*) ideal shock tube flows, and (*iv*) deflagrations initiated at a closed end. The method is particularly applicable for finding the perturbations due to relatively thin wall boundary layers.—(1.9.3×1.5.1×1.2.3.2).

Experimental investigation of the heat-transfer rate to a series of 20° cones of various surface finishes at a Mach number of 4·95. *J. J. Jones. N.A.S.A. Memo* 6-10-59*L. T.I.L.* 6461. *June* 1959.—(1.9.1).

Distribution of heat transfer on a 10° cone at angles of attack from 0° to 15° for Mach numbers of 2·49 *to* 4·65 *and a solution to the heat-transfer equation that permits complete machine calculations. P. B. Burbank and B. L. Hodge. N.A.S.A. Memo* 6-4-59*L. T.I.L.* 6467. *June* 1959.—(1.9.1).

WINGS AND AEROFOILS—*see also* BOUNDARY LAYER
INTERNAL FLOW

Basic pressure measurements at transonic speeds on a thin 45° sweptback highly tapered wing with systematic spanwise twist variations: wing with cubic spanwise twist variation. J. P. Mugler. N.A.S.A. Memo 5-12-59*L. T.I.L.* 6453. *June* 1959.
Pressure data are presented which were obtained in the Langley 8 ft. transonic pressure tunnel. Tests were made at Mach numbers from 0·800 to 1·200 at stagnation pressures of 1·0 and 0·5 atmosphere and at angles of attack from −4° to 12°.—(1.10.2.2×1.6.1×2).

Chordwise pressure distributions over several N.A.C.A. 16-series airfoils at transonic Mach numbers up to 1·25. *C. L. Ladson. N.A.S.A. Memo* 6-1-59*L. T.I.L.* 6454. *June* 1959.
A two-dimensional wind tunnel investigation of the pressure distributions over several N.A.C.A. 16-series aerofoils with thicknesses of 4, 6, 9 and 12 per cent of the chord and design lift coefficients of 0, 0·2 and 0·5 has been conducted in the Langley aerofoil test apparatus at transonic Mach numbers from 0·7 to 1·25. The tests ranged in Reynolds number from $2{\cdot}4\times10^6$ to $2{\cdot}8\times10^6$ and in angle of attack from −10° to 12°. Chordwise pressure distributions and schlieren flow photographs are presented without analysis.—(1.10.2×1.2.2×1.6.1).

*Low-speed investigation of blowing from nacelles mounted inboard and on the upper surface of an aspect-ratio-*7·0 *35° swept wing with fuselage and various tail arrangements. T. R. Turner et al. N.A.S.A. Memo* 5-1-59*L. T.I.L.* 6470. *June* 1959.—(1.10.2.2×1.3.4×1.8.2.2).

Thin airfoil theory based on approximate solution of the transonic flow equation. J. R. Spreiter and A. Y. Alksne. N.A.C.A. Report 1359. 1958.
A method is presented for the approximate solution of the nonlinear equations of transonic flow theory. Solutions are found for two-dimensional flows at a Mach number of one and for purely subsonic and purely supersonic flows. Results are obtained in closed analytic form for a large and significant class of non-lifting aerofoils.—(1.10.1.1).

Effect of standing vortex on flow about suction aerofoils with split flaps. P. Mandl. N.R.C. Report L.R.-239. *Jan.* 1959.—(1.10.1.1×1.1.5.1×1.2.4).

A wing-submerged lifting fan: wind tunnel investigations and analysis of transition performance. R. L. Wardlaw and N. V. McEachern. N.R.C. Report L.R.-243. *April* 1959.
Wind tunnel force measurements have been carried out on a wing-fan combination; the high solidity fan was embedded in a two-dimensional symmetrical wing, with the fan axis normal to the wing chord-plane. Results are discussed and compared to a simple momentum theory, with a view to their usefulness in V.T.O.L. project studies.—(1.10.2.1×1.5.1).

TESTING AND INSTRUMENTS

A frost-point hygrometer for supersonic wind tunnels (with addendum). D. Beastall and A. Winyard. R. & M. 3112. 1959.—(1.12.1.3).

Initial investigations into the suppression of flow separation in the 4 ft. 6 in. by 3 ft. 6 in. R.M.T.C. wind tunnel. W. D. Doble. A.R.L. Note A 169. *Oct.* 1958.—(1.12.1.1).

Techniques of flow visualization using water as the working medium. D. W. Clutter et al. Douglas Report E.S. 29075. *April* 1959.—(1.12)

Short notes contributed to the Pressure Measurements Meeting sponsored by the AGARD Wind Tunnel and Model Testing Panel. AGARD Report 163. *March* 1958.
A collection of 31 Papers, dealing with various aspects of pressure measurement, contributed by authorities from various NATO countries. The following subjects are dealt with: Aerodynamic aspects of pressure pick-ups and yaw meters; Pressure transducers; Liquid tube manometer and manometer reading devices; Pressure integrating devices; Pressure switches and plugs; Calibration problems; Measurement of fluctuating pressures; Complete systems and data handling; Mach number gauges.—(1.12.5×1.12.6.1).

Manometre a capacite pour la mesure des pressions rapidement variables. A. Moutet. AGARD Report 171. *March* 1958. *(In French).*
Pressure measuring equipment, developed by the O.N.E.R.A. for investigation of combustion instability phenomena in ramjets and rockets, is described. The problems of calibration are discussed and the results of applications in the fields of internal and external aerodynamics are given.—(1.12.6.1).

AEROELASTICITY

See also AERODYNAMICS—WINGS AND AEROFOILS

Esquisse des bases theoriques de l'essai de vibration au sol. R. Mazet. AGARD Report 184. *April* 1958. *(In French).*
The structure, assumed to be linear, is defined on the basis of an "associated conservative structure" (AS) obtained by disregarding any internal viscosity. The response to a harmonic excitation is examined and the overall characteristics are deduced. The response of the structure to a percussive or a plucking excitation is also discussed. The control surfaces raise special problems because of the variable characteristics of mass and stiffness of their linkages. The concept of mass balancing is defined and discussed. The case of servo-controls is mentioned but not developed. Data on the behaviour of the aircraft elastically suspended are given, and measures to avoid any appreciable disturbing effect due to suspension are indicated. It concludes with a theoretical justification of certain ground measurement methods particularly suitable for use with small models.—(2).

AIRCRAFT OPERATION

See also AVIATION MEDICINE

Safety and safety factors for airframes. A. M. Freudenthal. AGARD Report 153. *Nov.* 1957.
The concept of structural safety of airframes is analysed on the basis of its relation to the probability of structural failure, with a view of establishing procedures of quantitative evaluation of safety factors for a predetermined "acceptable" risk of failure. The difference in the approach to the concept of safety for ultimate strength and for failure is discussed, considering recent developments in fatigue research, particularly the results of fatigue tests under random loading, and methods of safety analysis for both conditions are proposed.—(5.3×31.2.3).

Schalldämpfung von Forschungs-und Entwicklungsanlagen für Strahltriebwerke. H. Dahlen and W. Lohse. D.F.L. Bericht 112. 1959. *(In German)*—(5.6).

EXTRA-ATMOSPHERIC TECHNOLOGY

See MATHEMATICS

AVIATION MEDICINE

Human tolerance to rapidly applied accelerations: a summary of the literature. A. M. Eiband. N.A.S.A. Memo 5-19-59E. *T.I.L.* 6455. *June* 1959.
Data applicable to space flight and to crash impact forces were obtained from a literature survey and analysed and discussed. These data are compared and presented on the basis of a trapezoidal pulse to show the effects of body restraint and of acceleration direction, onset rate, and plateau duration on the maximum tolerable magnitude of rapidly applied accelerations.—(9×5·3).

FLIGHT TESTING

*Some results of flight tests with the TU-*104. *G. Bock. AGARD Report* 202. *April* 1958.
Some of the main facts reported recently in the Soviet periodical *Cival Aviation* about the Russian low-wing jet transport, the Tu-104, are summarised.—(13).

On the extraction of stability derivatives from full-scale flight data. J. K. Zbrozek. AGARD Report 190. *April* 1958.—(13.2).

The full-scale air drag of some flying-boat seaplanes. A. G. Smith. R. & M. 3082. 1959.
An analysis has been made of the full-scale measured drag and lift performance data available on the Sunderland, Solent, Shetland, Sealand, Saro E.6/4 and Princess boat seaplanes, which all have hulls of fairly orthodox length/beam and fineness ratios but different degrees of aerodynamic fairing.—(13.3).

FUELS AND LUBRICANTS

Survey of hydrogen combustion properties. I. L. Drell and F. E. Belles. N.A.C.A. Report 1383. 1958.
Data on flame temperature, burning velocity, quenching distance, flammability limits, ignition energy, flame stability, detonation, spontaneous ignition, and explosion limits are presented. New material presented includes: theoretical treatment of variation in spontaneous-ignition lag with temperature, pressure, and composition, based on reaction kinetics of hydrogen oxidation; and calculated adiabatic flame temperatures over the hydrogen-air composition range for 0·01 to 100 atmospheres and initial temperatures of 0° to 1400°K.—(14).

HYDRODYNAMICS

Water-landing characteristics of a reentry capsule. J. R. McGehee et al. N.A.S.A. Memo 5-23-59L. *T.I.L.* 6471. *June* 1959.—(17).

MATERIALS

Measurements of total hemispherical emissivity of several stably oxidized nickel-titanium carbide cemented hard metals from 600°*F. to* 1600°*F. W. R. Wade and F. W. Casey. N.A.S.A. Memo* 5-13-59L. *T.I.L.* 6466. *June* 1959.
The measurements are presented for both as-received and polished test specimens together with a brief description of the equipment and procedures used.—(21.2.3).

Compressive strength of stainless-steel sandwiches at elevated temperatures. E. E. Mathauser and R. A. Pride. N.A.S.A. Memo 6-2-59L. *T.I.L.* 6472. *June* 1959.
Experimental results are presented from crippling tests of specimens in the temperature range from 80°F. to 1200°F. The specimens included resistance-welded 17-7 PH stainless steel sandwiches with single corrugated cores, type 301 stain-17-7 PH stainless steel sandwiches with honeycomb cores. The experimental strengths are compared with predicted buckling and crippling strengths.—(21.2.3×33.2.4.14.9).

A survey of data on the fatigue properties of D.T.D. 363 *and L.* 65 *(D.T.D.* 364*) aluminium alloys. J. Y. Mann. A.R.L. Note S.M.* 248. *Nov.* 1958.
Rotating cantilever and direct stress fatigue data for aluminium alloys to Specifications D.T.D. 363 and L. 65 (D.T.D. 364) in both the unnotched and notched condition are summarised. Direct stress information for L. 65 is extremely limited, while that for D.T.D. 363 is even more meagre.—(21.2.2×31.2.2.3.2.1).

The behaviour of fine copper nickel-alloy wires with negative temperature coefficients of resistance. W. Wiebe. N.R.C. Report M.S.-100. *Feb.* 1959.
A study was made of the behaviour of fine copper-nickel alloy wires with negative temperature coefficients of resistance during heat treatment. Appended is a brief survey of information available on experimental and commercial strain gauges, alloys and adhesives for use at elevated temperatures.—(21.2.2).

MATHEMATICS

Three-dimensional lunar mission studies. W. H. Michael and R. H. Tolson. N.A.S.A. Memo 6-29-59L. *T.I.L.* 6473. *June* 1959.
Three-dimensional lunar trajectories have been calculated by integration of the equations of motion of the classical restricted

three-body problem of celestial mechanics. The calculations have been used for analysis of several aspects of lunar flight, including requirements for achieving lunar impact and for establishment of a close lunar satellite. Some effects of errors in the initial conditions on the characteristics of lunar satellite orbits are discussed.—(22.3×25.2×8).

A variant to Fibonacci's sequence. J. Guest. A.R.L. Note S.M. 250. *Feb.* 1959.—(22.1).

Transfer-function discovery on the PACE analogue computer. J. H. Milsum. N.R.C. Report MK-2. Feb. 1959.
Experimental work on the PACE analogue computer has shown that, by a "mask" matching technique, the unknown constants of a transfer function, up to a maximum number of four, may be readily determined within a few minutes to any desired accuracy (certainly within 1 per cent). The conventional transient and frequency responses are immediately obtainable from the transfer function, so that the method is more general than one which obtains only, for example, the frequency response.—(22.1).

METEOROLOGY

See SCIENCE—GENERAL

MISSILES

See MATHEMATICS

POWER PLANTS

See also AERODYNAMICS—INTERNAL FLOW
THERMODYNAMICS

Analytical investigation of the effect of turbopump design on gross-weight characteristics of a hydrogen-propelled nuclear rocket. H. E. Rohlik and J. E. Crouse. N.A.S.A. Memo 5-12-59*E. T.I.L.* 6465. *June* 1959.
Axial flow, mixed flow, and centrifugal pumps driven by single- and twin-turbine drive systems were investigated for application in a high pressure bleed-type turbo-pump unit. The effects of turbo-pump weight and turbine flow rate required for each type are shown in terms of the ratio of rocket gross weight to payload for a fixed mission.—(27.3).

Air-cooling methods for gas-turbine combustion systems. F. J. Bayley. R. & M. 3110. 1959.
Each of the different methods of wall cooling is discussed and the theory and mechanism of the cooling process is developed from first principles. Certain of the methods have been the subjects of experimental investigations and in such cases a brief description of the test is given. Sufficient information is given to enable any of the various methods to be applied to practical wall-cooling problems and their relative advantages and disadvantages for gas turbine applications are considered.—(27.1).

Application of direct engine thrust measurements in supersonic and hypersonic flight regimes. H. R. Dettwyler. AGARD Report No. 195. *April* 1958.
The design philosophy and actual flight experience of a direct thrust measuring device is discussed as applied to a supersonic test vehicle utilised as a developmental ram-jet flight test bed. Some characteristic outputs of this device are discussed wherein the true flight performance of air-breathing engines is to be defined and/or documented over supersonic and hypersonic Mach numbers.—(27.0.2).

FATIGUE

EXPERIMENT—*see also* AIRCRAFT OPERATION
MATERIALS

Experimental investigation of effects of random loading on the fatigue life of notched cantilever-beam specimens of 7075-*T6 aluminium alloy. R. W. Fralich. N.A.S.A. Memo* 4-12-59*L. T.I.L.* 6458. *June* 1959.
Fatigue results are presented for both constant-amplitude and random loading. These results are compared on the basis of time to failure, where an equivalent time to failure based on the natural period of vibration is used for the constant amplitude tests. A theoretical result for random loading is also compared with the experimental results.—(31.2.2.3.2.1).

Resistance a la fatigue d'un collage metal—metal a simple recouvrement. L. Locati. AGARD Report 180. *April* 1958. (*In French*).
The behaviour of glued steel sheets under alternating stress is considered. The test pieces were subjected to alternating and intermittent stress in a range of cycles from 0·25 (static strength) to a million. The occurrence of fatigue rupture in metal-metal glued joints is discussed, as well as the effect on fatigue strength of the various ageing treatments used for some of the test pieces. The fatigue strength values for glued joints are compared with those for riveted joints.—(31.2.3.2.4).

SCIENCE—GENERAL

Sporadic E ionization. B. Landmark (Ed.). AGARDograph 34. 1958.
The world-wide occurrence of sporadic E is dealt with and suggested theories are outlined. A number of papers are given on experimental studies of sporadic E by means of various techniques. The possible mechanisms of ion production are discussed.—(32.2.1×24).

STRUCTURES

THEORY AND ANALYSIS—*see also* MATERIALS

Determination of static strength and creep buckling of unstiffened circular cylinders subjected to bending at elevated temperatures. E. E. Mathauser and A. Berkovits. N.A.S.A. Memo 6-14-59*L. T.I.L.* 6464. *June* 1959.
A method based on a semi-empirical procedure is presented. The method is applicable to cylinders that are loaded into the inelastic stress range prior to buckling and fail in a local mode. Predicted bending moments associated with static strength and creep buckling are compared with published experimental data obtained from tests at 500°F. on 5052-0 aluminium alloy cylinders with radius thickness ratios ranging from 125 to 250.—(33.2.4.3.2×33.2.4.3.9).

Transient thermal stresses in an elastic half-space. C. H. J. Johnson. A.R.L. Report M.E. 89. 1958.
Expressions for the transient thermal stress distributions within an elastic half-space for three cases of temperature boundary conditions are obtained. The three temperature boundary conditions are: (*i*) Uniform constant temperature on the boundary plane, (*ii*) Uniform constant flux on the boundary plane, (*iii*) "Radiation" to the boundary to the bounding plane from a medium at constant temperature.—(33.2.4.0.9).

*A preliminary analysis of the penalties associated with piercing a wing torsion box with a grid of holes. A. H. Hall. N.A.E. Report LR-*236. *Jan.* 1959.
This analysis relates to a conventional aircraft that is modified by the addition of fans housed in the wing plane to provide means for vertical take-off and landing. The influence of a grid of holes in the wing torsion box, on top level speed, is inferred by the torsional stiffness criterion for wing divergence. The probable weight penalty incurred in restoring the stiffness to its original, or an intermediate value, is estimated.—(33.2.3.1.5×33.4.1).

*Analysis of a cantilever beam developing an isoplastic response under impact at the tip. A. H. Hall and V. L. Saxon. N.R.C. Report LR-*237. *May* 1959.
A condition of isoplasticity is defined for a beam as the development of plastic strains simultaneously at all points along the profile fibres. Two conditions must be satisfied simultaneously, one on the profile shape, and one on the mass distribution.—(33.2.4.1.2×33.2.2).

Biegeeigenfrequenzen eines gelenkig gelagerten Balkens. Torsionseigenfrequenzen von Kreisscheiben veränderlicher Dicke. H. Wittmeyer. S.A.A.B. T.R. 3. 1959. (*In German*).—(33.2.4.1.2×33.2.4.5.5).

WEIGHT ANALYSIS AND CONTROL—*see* THEORY AND ANALYSIS

THERMODYNAMICS

Effect of ozone addition on combustion efficiency of hydrogen-liquid-oxygen propellant in small rockets. R. O. Miller and D. D. Brown. N.A.S.A. Memo 5-26-59*E. T.I.L.* 6460. *June* 1959.—(34.1.1×27.3).

APPOINTMENTS

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